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Executive Summary

Background: The Office of Naval Research Capable Manpower Program is developing technologies to support the process of decision making in submarine teams. Specifically, tools are being developed to support submarine planning and navigation. This technical report fills a small but critical gap in the development of technologies for submarines by examining the organization of submarine teams from a systems perspective to better understand information flow and decision making within each team. This report develops the systems foundation for models of submarine planning and navigation.

Method: This technical report uses Beer's Viable System Model to develop models of information flows and decision making in the conduct of submarine operations.

Results:

1. The submarine is a viable system in the sense that it is an organization designed for the purpose of adapting to a changing environment and sustaining itself while producing needed outputs within a nested hierarchy of systems. It remains viable only so long as essential elements of the system are maintained within allowable physiological limits (See Homeostasis Principle in Skyttner, 2005).
 - a. Information is what flows throughout the Viable Submarine System and enables the system to make the decisions necessary to sustain its output in continually changing circumstances. It is fundamental to the control features of the viable system.
2. The purpose of the Viable Submarine System is to produces outputs in three dimensions.
 - a. Operational Dimension
 - i. $O_{Passive}(geo, t)$, Passive Operational Presence at a Given Place and Time.
 - ii. $O_{Active}(geo, t)$, Active Operational Presence at a Given Place and Time.
 - iii. $O_{Latent}(geo, t)$, Latent Operational Presence at a Given Place and Time.
 - b. Technological Dimension
 - i. $T_{Availability}(comp, t)$, Availability of Technology for a Given Component and Time.

- ii. $T_{QA}(comp, t)$, Quality Assurance for Other Organizations Providing Technological Availability for a Given Component and Time.

c. Human Dimension

- i. $H_{ProfDev}(member, t)$ Develop the Professional Skills of Crew Members over Time.
- ii. $H_{Technology}(comp, member, t)$, Develop the Technical Skills of Crew Members for a Given Component and Time.
- iii. $H_{Operations}(mission, member, t)$, Develop the Operational Skills of Crew Members for a Given Mission and Time.

3. The submarine and its crew are the System-in-Focus for this analysis.
4. In the operational dimension, the submarine watch sections are the viable subsystems that produce the operational outputs of the Viable Submarine System. At this level of recursion, the only difference between the watch sections of different submarine classes (and naval ships in general) is that the specific missions assigned will be relevant to the range of operational capabilities that the submarine system can achieve.
 - a. The environment of the viable submarine watch section subsystem is all information received by the submarine during the time period that the watch section is on duty. In the geographic sense, the environment is bounded in time and space. In an information sense, the environment is bounded by communications and sensor signals received. In a ship and war fighting sense, the environment is bounded by the actions of other vessels, warships, sensors, and weapons that are sensed or believed to exist.
 - b. The operations of the viable submarine watch section subsystem are amplified by a relatively small set of transducers as it acts to adapt to its environment and produce its output. The watch section can choose its three-dimensional path by employing the submarine's control surfaces and mode of propulsion. The watch section can choose to communicate with the environment. The watch section can launch human or mechanical probes into the environment that range from SEAL warfighters and torpedoes to salinity and temperature probes. The greatest overall amplifier of a submarine's operations is its stealth. As long as human elements in the environment are unaware of its presence, the submarine is able to control the pace of its interactions with the environment.
 - c. The Command and Control (C2) element of the viable submarine watch section acts as the interface between higher level C2 and the watch section and oversees Watch Section Operations. The C2 function creates a

negative feedback loop that monitors the required output of the viable watch section subsystem and makes corrections to achieve the desired output over time. The regulation function supports C2 by comparing actual output data to the plan (desired output). It requires a model of the viable watch section system interacting with its environment. The traditional model used by naval ships is the navigation chart.

- d. The Viable Submarine System places limits on each watch section. Submarine Force doctrine is communicated by the Commanding Officer's Standing Orders, the procedures of the ship's systems manual, various naval warfare publications and other governing doctrine that prescribe rules for submarine watch section behavior. Collectively, these represent a relatively stable set of rules for the watch section. Orders such as Commanding Officer's Temporary Standing Orders and specific Operation or Exercise Orders communicate temporary rules. Overall, these limits act to reduce the variety of viable submarine watch section behavior to within organizationally acceptable boundaries.
 - e. The submarine watch sections are held accountable for the required outputs of the Viable Submarine System during their watch. The progress of the ship, the communications received and transmitted and the sensors and weapons employed by the watch section all combine to produce the output of the Viable Submarine System. The performance of the watch sections is measured against the tasking that the submarine received from higher authority as communicated to the watch section in the form of a plan. The outputs that the watch sections are required to produce are typically communicated by and measured against the Commanding Officer's Night Orders and the submarine's approved plan of intended movement.
5. The Viable Submarine System contains damping functions that coordinate the actions of the watch sections so they do not hinder each other's operations. If these functions are perceived as prescribed limitations being imposed by higher level management upon watch section operations, then watch section autonomy is unnecessarily limited and the output of the Viable Submarine System is reduced. However, if these functions are perceived as working for the benefit of the watch sections, oscillations can be minimized while maximizing watch section autonomy.
- a. The primary source of oscillation or conflict arises when the actions of one watch section unnecessarily limit the freedom of action of the other watch sections. For instance, imagine that there are three things that the watch sections, as a group, are required to complete in 24 hours. If the first two watch sections fail to complete these actions, the remaining watch section may have to spend an inordinate amount of their efforts to meet the desired deadline. Damping functions help each watch section carry their share of the Viable Submarine System load.

- b. This report identifies and describes six categories of damping functions within the Viable Submarine System. The most important and hardest to quantify are the command climate felt by the watch section and the effective functioning of the chief's quarters.
 - c. The perceptions of the watch sections toward damping functions will vary from submarine to submarine according to the individual ship's command climate and chief's quarters. Overall, the sustained success of the Submarine Force as a whole is a strong indicator that, as a group, damping functions such as command climate and chief's quarters on submarines are functioning well. The autonomy of the watch sections (and the output of the system as a whole) suffers when the watch sections view damping functions as tasking from above.
- 6. The supervisors within the Viable Submarine System collectively comprise the Viable Submarine System Control function.
 - a. Viable Submarine System Control functions include:
 - i. Communication with the Operational Immediate Superior in Command (ISIC) about tasks.
 - ii. Receipt of reports from Watch Section Monitoring and Damping functions.
 - iii. Resource bargaining with the Watch Sections.
 - iv. Regulation of Watch Section Operations.
 - v. Of these management functions, most are absorbed in the daily work of submarine supervisors. Only the regulation function has a formal structure embodied in the ship's Daily Operations Brief.
 - b. Authority is communicated to the watch sections in the ship's Navigation Plan and Commanding Officer's Night Orders and augmented by verbal orders from appropriate submarine supervisors.
 - c. The Control function as represented in the Commanding Officer, Executive Officer, Chief of the Boat and Department Heads typically strikes the bargain for resources on behalf of each watch section by estimating the capabilities of the individual watch sections (and key individuals in the watch sections) as well as the capabilities of the submarine, as a whole, and chooses tasks that they assess to be within the capability of the watch sections assigned. Watch sections are expected to ask for help if they find that they cannot achieve the desired results.
 - d. The Officer of the Deck is responsible for the performance of the watch section.

- e. Submarines exercise formal monitor programs, informal monitoring, and monitoring of simulated operations. All three are required to provide Control with sufficient information about Watch Section Operations and to amplify Management expectations throughout the ship.
 - f. The officers exercising the submarine Control function are senior in rank and typically have more experience in submarine operations than the watch sections. There is a clear lead (Control) – follow (watch section) relationship.
 - g. The submarine's environment is dynamic. As a result, the watch sections must be granted sufficient autonomy to adapt to the changing environment while striving to achieve the tasks set out before them. For example, on a surface transit, submarine Control may task the watch section to arrive at Point B at a specified time. However, Control cannot predict dynamic conditions such as weather and the position of interfering surface vessels. As a result, submarine navigation plans try to identify all available navigable water in order to give the watch section maximum autonomy. The actual autonomy exercised by watch sections will depend on the circumstances and the actual System-in-Focus.
7. The Viable Submarine System Intelligence function looks outside the viable system and tests the ability of the submarine to meet future risks and opportunities.
- a. There are three components to the Intelligence function:
 - i. A communication channel with the likely future.
 - ii. A communication channel with an unlikely future that might affect future submarine system viability.
 - iii. A self-awareness of an internal model of the viable system that the Intelligence function uses to test the viability of the submarine system against future alternatives.
 - b. There is no set time span for how far ahead the Intelligence function considers. When the anticipated future is relatively stable or when there are sufficient resources available, the planning horizon may be months or even years in advance. When the environment is especially hard to predict and resources are strained, the planning horizon is likely to be much shorter.
 - c. It is difficult to gauge how well these activities support adaptation of the Viable Submarine System to the future. The demonstrated long-term viability of the basic submarine system indicates that this function is adequately addressed. On the other hand, it is hard to point to specific aspects of the Submarine Force doctrine or organization that support this function, with the notable exception of Operational Risk Management.

We speculate that a tremendous amplifier of U.S. submarine viability is its technological advantage against virtually all adversaries. In many ways, U.S. submarines can ignore many aspects of their environment. Should this advantage degrade, then we predict that the Intelligence function would sense greater risk and submarine viability would be more difficult to maintain.

- d. The effectiveness of the Intelligence function will change from submarine to submarine and one can only point again to the long-term success of the Submarine Force to say that it must be adequately addressed, on the whole.
 - e. While there is a formal structure for Watch Section Operations (pre-watch tour, turnover checklists, etc.), there is no formal structure for bringing together internal and external information for long-term decision making. Most submarines have a daily operation brief, but its intent is not long range planning or assessment. The success or failure of any given submarine in this area is dependent upon the proclivities of the officers and crew to plan for the submarine's future.
 - f. Urgent developments are typically sensed by members of the watch section in the performance of their duties. There are various standing orders and regulations that require Commanding Officer notification of various events such as equipment failures, detection of threats, receipt of operationally urgent messages or tasking, etc.
8. The Commanding Officer embodies the Command function on a submarine. The Commanding Officer acts to make all critical decisions that affect the viability of the submarine. These decisions take the form of direct orders (both oral and written) and approval of plans and decisions created by the Control function.
- a. The Commanding Officer is the sole person who can speak for the entire Submarine Viable System
 - b. The Intelligence function must decide how much and how often to sample the future environment. There is also a need to decide how much effort to expend on the likely future and how much effort on the risk and opportunities of less likely events. The decision-making style of the Commanding Officer will largely influence how much effort Intelligence places on various probes of the future environment.
 - c. Command's use of the adaptation mechanism will heavily influence the relationship between Intelligence and Control. In fact, since there is no formal Intelligence organizational structure on the submarine, there is great risk that there will be little consideration of the Intelligence function unless the Commanding Officer demands it. A healthy, constructive debate between Intelligence and Control is the key to long-term system viability.

- d. The Commanding Officer's relationship with the Watch Section Sub-systems is a key component of the communication of the submarine's purpose and identity. The Commanding Officer spends time interacting with the next higher operational recursion in order to anticipate the needs of and understand the identity of the higher-level system in which the submarine is embedded. The Commanding Officer and the Watch Section Sub-systems need the same systems connection so that the watch sections can anticipate the needs and understand the identity of the Submarine Viable System.

Models of Decision Making in the Submarine Information Architecture

This research employs Beer's Viable System Model (Beer, 1979, 1981, 1985) to construct conceptual models of decision making in the VIRGINIA Block III Command and Control Center (CACC). These models will represent the interaction of human teams and technology in the VIRGINIA submarine CACC as a non-linear complex system and will create a systems-based theory of how information flows and decisions are made. Once validated, future research will demonstrate how these models can be used to make qualified predictions about how changes in technology will affect the submarine decision-making process.

A Systems-Based Foundation for Submarine Decision Making

Complex systems, like submarine information architectures, display several key characteristics (Richardson, 2005). First, complex system behavior is strongly influenced by the system's history. What worked for the system in the past affects the behavior of the system in the present. Second, complex systems display a wide range of qualitatively different behaviors. Systems that seem incomprehensible at the microscopic level are often more predictable when analyzed at the macroscopic level. Third, complex systems are inherently non-linear. Their behavior can be remarkably stable in many circumstances and yet, sometimes small changes in the system will result in large changes in behavior. Fourth, complex systems are fundamentally incompressible. Models can represent key aspects of a complex system but they cannot represent the rich complexity of the entire system. Choosing what to represent and what to leave out is a critical step in building complex system models and theories. The test of a model is not whether it is *true*, but instead whether it is *useful* (Beer, 1985). Submarine information architectures display all four of these characteristics.

History. Submarine watch section behavior is rooted in submarine history. The rules and procedures that govern the actions of submarine watch sections have evolved from over 100 years of U.S. submarine experience. Everything from phraseology ("Last man down, hatch secure!") to procedures ("Emergency Deep!") is laden with the lessons learned by submariners in the past. The Submarine Force's concern for retaining the lessons of submarine history is strongest when faced with large technological changes. The VIRGINIA Class submarine presented a significant technological leap in the design of submarines. The hydraulics and air systems that moved the submarine's rudder and control surfaces were replaced with fly-by-wire computer technology. Paper procedures were replaced with laptop computers. The helmsman was replaced with a pilot. As the watch section procedures for operating VIRGINIA Class Submarines were undergoing final fleet review, Commander Submarine GROUP TWO (COMSUBGRU TWO) instituted a dedicated review of the technical content of VIRGINIA's procedures specifically to ensure that the phraseology, the doctrine, and the lessons learned from years of submarine operations were carried forward by VIRGINIA watch sections.

In addition to this larger sense of history, there is also a more local sense of history that affects watch section behavior. How much rest has the watch section had prior to watch? What rules and procedures were being followed on the last watch? What behaviors were successful the last time the watch section faced this situation? Questions like these are all relevant when trying to understand and model watch section behavior. Submarine

commanding officers (COs) are taught to be sensitive to the effects of local history on their crews and themselves. Crews are taught to conserve their energy or “battle rest” in protracted tactical engagements. Submariners are required to tour their spaces and talk to off going watch standers to learn what has changed since that last time they stood watch. This anecdotal evidence strongly substantiates the role of history in the decision-making ability of the submarine information architecture.

Wide-Ranging Scale-Dependent Behavior. While complex systems may display widely varying qualitative behavior, the phenomenon tends to be scale dependent (Richardson, 2005). Phenomena that vary in a microscopic view may seem well ordered from a more macroscopic perspective. Submarine crews display scale-dependent behavior. Despite a strong, shared culture and well-defined procedures, the experience of most submariners is at the microscopic level. Each crew is qualitatively very different. The leadership traits and personality of each CO creates a unique command environment. The day-to-day behavior of the wardroom sets priorities and expectations for the crew that the chief petty officers of the ship enforce. The individual experiences of submariners are strongly affected by individual personalities. Yet, the experience of Submarine Force inspection teams, at a more macroscopic level, is that submarine teams are very similar. Common strengths and weakness are much more apparent when viewed from a fleet perspective.

Submarine information architectures have proven remarkably resistant to change (non-linear performance). Even though dozens of combat system upgrades have been fielded over the past 30 years of digital combat system development, experienced submarine crews with older combat systems often perform on par with crews afforded the latest technology. Systems science labels this phenomenon as the Basin of Stability Principle (Skyttner, 2005b). Complex systems often display remarkable stability in performance in the face of changing system inputs and environmental conditions. However, regions of instability typically surround basins of stability. This suggests that unstable or problematic information architecture performance is not a failure of the system to achieve predictable output but inadequate system adaptability in the face of environmental change.

Incompressibility. The most fundamental limitation in any modeling attempt of the submarine information architecture is the inability to create models of complex systems that are less complex than the system itself. In the strictest ontological sense, there is no submarine information architecture; there is just the world as one large complex system. However, our understanding of the submarine information architecture can only advance if we construct theories and test models of the architecture. The key point here is that models are constructs independent of the real world.

Existing Models of the Submarine Information Architecture

Many models of the submarine information architecture have been constructed for various purposes. One way to model the VIRGINIA submarine information architecture is to view the spatial arrangement of the VIRGINIA CACC (See Figure 1). This perspective emphasizes the physical attributes of the VIRGINIA information architecture such as the size and orientation of workstations. One can see how watch standers are

placed and view the physical distance between members of a team. Models such as these are particularly useful when building ship drawings and estimating construction costs.



FIGURE 1. An Artist's Rendering of the VIRGINIA Block III Submarine Command and Control Center (Hamburger, Miskimens, & Truver, 2010)

Another way to model the VIRGINIA information architecture is to view the functional decomposition or “wiring diagram” of the crew. There are two organizational structures within each submarine crew. The administrative organization divides a submarine crew into departments (executive, weapons, navigation, engineering, and supply) and then subdivides departments into divisions. The function of the administrative organization is primarily to sustain the crew and maintain the ship. The operational organization of the ship varies with the ship’s mission. Some ship missions, such as the piloting of the ship close to land and short duration high intensity combat situations require the entire crew to be awake and manning various operational functions. These watch standing organizational structures are known as the “maneuvering watch” and “battle stations” respectively. However, most submarine operations (and therefore most operational decisions) are executed within a three-section watch rotation. It is the watch section of the ship that makes the moment-by-moment decisions that operate the submarine. Models like these are used to monitor and maintain the manning of the submarine.

The VIRGINIA Non-Propulsion Electronics System architecture creates requirements and structure for the integration of technical systems within the VIRGINIA CACC. This type of high-level mapping of requirements is the most common form of information architecture modeling (Brancheau & Wetherbe, 1986; Wang, 1997). The VIRGINIA Class Submarine Program Office created this model in the 1990s to take advantage of the rapid advance of Commercial-Off-the-Shelf (COTS) technology. They wanted to create the first submarine architecture specifically designed into the combat system to control information flow between the multiple subsystems in a submarine control room. The VIRGINIA Class Program established standards for the network (Asynchronous Transfer Mode Switching), the middleware (Common Object Request Broker Architecture), and network management protocols (Simple Network Management Protocol) which created a

data ring through which the federated subsystems of the VIRGINIA Class control room connected in a true system of systems architecture (Pallack, Bussiere, Conrad, & Nunes, 2008). The VIRGINIA architecture design has been so successful in integrating submarine subsystems in a rapid and cost-effective manner that Program Office Executive, Submarines has directed the development of a Submarine Warfare Federated Tactical System (SWFTS) that creates a common submarine information architecture across VIRGINIA, SEAWOLF, Los Angeles Class, OHIO Guided Missile Submarines and TRIDENT submarine classes (Pallack et al., 2008).

From a human perspective, over twenty years of U.S. Navy research into topics of team training and human performance have yielded many breakthroughs in our understanding of the core processes that command and control (C2) teams use to communicate, coordinate, and monitor their own performance. These research efforts have resulted in advances in crew resource management and structured developmental feedback for team training that are now widely used in the training of submarine combat teams (Goodwin, Burke, Wildman, & Salas, 2009).

Problem Statement

Despite the successes of these earlier models, we still struggle to understand how submarine crews manage the complexity of the undersea environment. Steed, Marquet, & Armbruster (2010) argue that the increasing variety in submarine operating areas, mission assignments, and assortment of targets combined with an increasing volume of sensor data to process is driving submarine crews to their cognitive limits. They argue that our legacy of centralized decision making must be re-examined. We need a decision-centric model to help integrate the data-driven capabilities of the SWFTS engineering architecture with our understanding of individual and team cognition. This research proposes a system-based approach to bridge the gap between our ability to engineer data architectures and the ability of teams to operate effectively. This approach is complementary to existing efforts in information architecture engineering and team performance measurement and training.

Beer's Viable System Model

Stafford Beer's Viable System Model (Beer, 1979, 1981, 1985) is a well-established theory that has proven particularly useful in focusing on issues of organizational C2 (Jackson, 2000). It requires practitioners to identify which parts of the complex system produce the outputs of the system. It recognizes the need to manage complexity and the flow of information throughout the architecture as well as the dynamic, time-constrained nature of making decisions that affect system viability.

The principal difficulty in modeling any information architecture is in determining what aspects of the architecture to model and what aspects to leave out. There are almost an infinite number of possible models and researchers can quickly become lost in the details of the modeling effort without capturing the essential characteristics of decision making in the control room. This is where the Viable System Model (VSM) provides several key advantages. First, the VSM starts with a normative model composed of five subsystems that prescribe what any complex system must have in order to maintain viability. Employing the VSM is not so much an effort of creating a model from scratch as it is

interpreting how the complex system being studied should be represented within the VSM's language and structure. The normative structure of Beer's model is also what generates its inherent diagnostic power. If the system being studied lacks key features of the ideal model, then the system under study has a fundamental weakness that can be explained by the theory that the VSM is based upon.

Another advantage of the VSM is its recursive structure. Complex systems, like the submarine information architecture, display scale-dependent behavior. Because the VSM is recursive, it can be focused at the most appropriate scale for the characteristic being modeled. As a result, the model does not need to represent every detail of the entire information architecture to be useful; it only needs to represent essential aspects of the complex system at the most important scale.

The final advantage of the VSM is that it makes strong, testable claims. It is possible to test hypotheses derived from the model in order to substantiate its usefulness. Once tested, a model of decision making in the Virginia Block III information architecture design can be used to diagnose the strengths and weaknesses of the architecture and evaluate the probable impacts of proposed changes on watch team decision making.

Beer's VSM is based on two key concepts, one organic and one cybernetic. Drawing upon organic concepts of viability and survival, the VSM assumes the same set of rules that govern whether an organism can remain viable apply to an organization of organisms at higher levels of recursion (Beer, 1989). Drawing upon cybernetic principles of requisite variety (Ashby, 1957), the VSM proposes that a system is viable (continues to produce its output) if and only if it can regulate itself sufficiently to respond to the variety of threats posed by its environment (Waelchli, 1989). As a result, there are essentially three categories of components within Beer's model: environmental (everything external to the system), operational (the parts of the system that produce its output), and managerial (the parts of the system that regulate the system).

The core structures of Beer's VSM are the subsystems that actually produce the VSM's output. These subsystems are the key structures that link viable systems to lower levels of systems recursion. This occurs because each subsystem is a viable system in its own right. For example, the Submarine Force, Atlantic Fleet (COMSUBLANT) is responsible for manning, training, and equipping roughly 28 submarines (20 attack submarines (SSNs), 6 ballistic missile submarines (SSBNs), and 2 Guided Missile Submarines (SSGNs)) for their missions. Within the COMSUBLANT organization, COMSUBGRU TWO is responsible for the 20 SSNs and COMSUBGRU TEN is responsible for the 6 SSBNs and 2 SSGNs. In this example, COMSUBLANT is a viable system. The changing demands of submarine missions, the various impacts of maintenance failures, variable weather conditions, and the schedule for deployments required by Fleet Forces Command are all part of COMSUBLANT's environment. COMSUBGRU TWO and TEN are subsystems producing trained and ready submarines for COMSUBLANT. COMSUBLANT Staff manage their system by monitoring the changing demands of the environment and tasking the work of COMSUBGRU TWO and TEN.

This VSM description of COMSUBLANT also demonstrates the recursive nature of the VSM. COMSUBGRU TWO and TEN are both subsystems within the COMSUBLANT viable system and viable systems in their own right. Submarine Group Commands (as a

viable system) rely on Submarine Squadron Commands (as subsystems) while Submarine Squadron Commands (as viable system) rely on the submarines themselves (as a subsystem). A key early step in VSM analysis is identifying the recursive nature of the viable system being studied and focusing the model at the most effective level of recursion to explore the system's issues of concern. In the case of submarine decision making, the Viable Submarine System must be deconstructed into recursive layers that mirror how the submarine crew organizes the aspects of decision making in which we are most interested.

The remaining components of the VSM represent regulatory mechanisms for managing environmental variety and sending signals to the subsystems as needed to adapt. One regulatory system coordinates the activities of the subsystems for the benefit of the viable system. Another regulatory system (Control) monitors the work of each sub-system, controls the resources that each sub-system requires and communicates with the manager of each subsystem in support of overall system viability. A third regulatory system (Intelligence) focuses on understanding the demands that the environment is placing on the viable system both now and in the future. The final regulatory system (Command) makes the decisions that will ultimately determine the viability of the system. The five components of the VSM are organized into a topological map as shown in Figure 2.

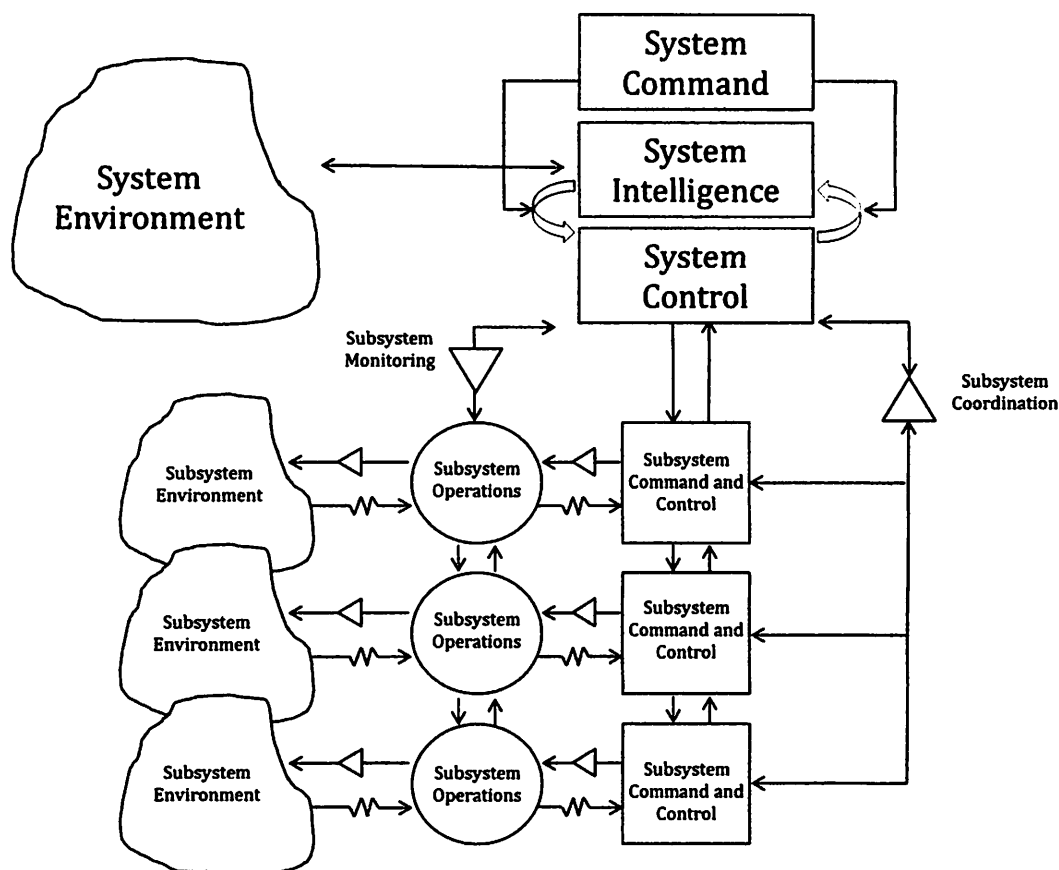


FIGURE 2. Viable System Model (Adapted from Beer, 1985)

Beer's VSM is particularly well suited to investigate the process of submarine decision making. For example, the VSM predicts that a critical struggle occurs at the decision making level of viable system management (Command). Command, the part of the system with the least variety, is responsible for ensuring overall system viability in the face of environmental threats with the most variety. In the case of the submarine watch section, this does not mean that the viable system decision maker (Officer of the Deck) has less variety or experience than other watch standers in the control room. It means that the decision maker has less capacity to handle environmental and operational variety than the entire control room acting as a team. VSM theory predicts that viable systems require an adaptation mechanism to reduce the complexity of the environment to a level of variety that Command can absorb (Espejo, 1989). Command requires Control to compare the recommended decision of the system with the Intelligence assessment of the environment. If Control and Intelligence agree, then Command has confidence that the decision is sound.

The adaptation mechanism predicted by the VSM closely mirrors the thinking of submariners as they evaluate surface contacts before coming to periscope depth. The watch section takes inputs derived from the ship's sensors and presents a picture of the contact situation to the Officer of the Deck (OOD). The OOD (often representing both the function of Intelligence and Command) compares the picture generated by the watch section to raw information presented on the sonar screen. If the picture is good enough to assure ship safety, the OOD requests permission to proceed to periscope depth.

Research Questions

This research proposes to follow the methodology established by Beer and others (1985; Jackson, 2000) for identifying and diagnosing the submarine information architecture as a viable system. This report addresses the following questions:

1. (Identify) Is a submarine a Viable System? If it is, then what defines the Viable Submarine System and what is the role of information and decision making within the Viable Submarine System?
 - a. What is the purpose of the submarine?
 - b. Recursion level 1 - What is the relevant viable system that meets the stated purpose? This is the System-in-Focus.
 - c. Recursion level 2 – What are the subsystems within the viable System-in-Focus that produce the stated purpose? These are the nuclei of the System-in-Focus.
 - d. Recursion level 0 – What is the next higher-level viable system in which the System-in-Focus is embedded?
2. (Diagnose) How does the Viable Submarine System compare to the ideal Viable System Model?
 - a. What are the subsystems within the Viable Submarine System?

- i. What are the relevant environment, operations, and C2 elements of each subsystem?
 - ii. What limits do higher authority place on each subsystem?
 - iii. How is each subsystem held accountable and how is performance measured?
 - iv. Diagram each subsystem according to the VSM rules.
- b. How is coordination of the subsystems regulated within the Viable Submarine System?
- i. What are the possible sources of oscillation or conflict between the subsystems?
 - ii. What is present within the System-in-Focus that provides a harmonizing or mediating effect?
 - iii. How is coordination perceived by the System-in-Focus?
 - iv. Model the coordination function according to the VSM.
- c. How is control of the subsystems achieved within the Viable Submarine System?
- i. What are the components of the Control function?
 - ii. How does the Control function exercise authority?
 - iii. How is the bargain for resources with each subsystem carried out?
 - iv. Who is responsible for the performance of each subsystem?
 - v. How does the Control function audit the performance of each subsystem?
 - vi. What is the relationship between the subsystems and the Control function?
How much autonomy does each subsystem exercise?
- d. How is the Intelligence function achieved with the Viable Submarine System?
- i. What are all the intelligence activities within the Viable Submarine System?
 - ii. How far ahead in time do these activities consider?
 - iii. How well do these activities support adaptation of the Viable Submarine System to the future environment?
 - iv. How effectively is the Intelligence function monitoring the future environment?
 - v. Is the Intelligence function open to novelty?

- vi. How well does the Viable Submarine System bring together internal and external information for decision making (adaptation mechanism)?
- vii. How does the Intelligence function alert Command to urgent developments in the Viable Submarine System?
- e. How is Command achieved within the Viable Submarine System?
 - i. Who is it and how do they act?
 - ii. Does Command embody the “identity” of the entire Viable Submarine System to the next higher level of the system (Recursion 0)?
 - iii. How do the expectations of Command affect the perceptions of the Intelligence function?
 - iv. How do the expectations of Command affect the relationship between Control and Intelligence functions?
 - v. Does Command share an identity with each subsystem in the Viable Submarine System?

The Viable Submarine System

Modern systems' thinking is rooted in the concept of holism. Its premise is that "the whole is greater than the sum of its parts." All systems are open, interconnected and part of the greater whole. No system can be known completely (Skyttner, 2005). As a result, any model or representation is by definition incomplete. The question then becomes not whether any given model is "true" or "false" (because all are false to some degree), but rather is it "useful" (Beer, 1985). The purpose of this research is to construct a model of a submarine as a system embedded (and containing) a hierarchy of systems dedicated to its operational mission and to use this model to examine the essential flows of information and decision making within that submarine system.

The fundamental problem that any viable system solves is how to produce its required output in the face of a complex and changing environment. If the environment is constant, then the viable system can be reduced to a preprogrammed set of responses to optimize the output. However, most environments are not constant. Many exhibit high levels of variety and variability over time. As a result, the system must sense the changes that are occurring and adapt its behavior to sustain its intended purpose. In system terms, the part of the system that senses changes and directs the actions of the viable system is called the controller. It is a governing principle of systems theory that "control can be obtained only if the variety of the controller is at least as great as the variety of the situation to be controlled" (Ashby cited in Skyttner, 2005: 100)¹.

Models of systems are best organized by understanding the system's interconnections with its environment, its purpose and its relationships within the hierarchy of systems that interact with respect to the purpose of interest (Beer, 1985, Skyttner, 2005). The submarine is the system that we will focus on. The questions we must address are: "What is the purpose of a submarine system?", "What system is the submarine embedded within?" and "What systems are embedded within the submarine system?"

In order to answer these questions, we must first consider a question of dimension. As human beings, we each have multiple dimensions or roles that we play. In one dimension, we are scientists or naval officers linked in our role of sustaining the strength of our Submarine Force. In another dimension, we are sons, daughters, fathers, and mothers linked in our roles as family members. Many of us have multiple dimensions as we play roles in volunteer organizations, alumni organizations, churches, etc. Systems, especially organizations, often have multiple dimensions as well (Beer, 1985).

Submarine systems are dominated by three dimensions (Figure 3):

1. Operations. This dimension defines the role that the submarine plays in peacetime and in war as a tactical unit of the theater anti-submarine warfare (ASW) commander. In Navy parlance, we call this relationship the operational chain of command. It is along this dimension that operational orders to the submarine are given and followed.

¹ This assumption is known as the Law of Requisite Variety.

2. Technology. This dimension defines the role that the submarine crew plays in sustaining the operational availability of the ship's equipment throughout its lifetime. This dimension exists within the administrative chain of command within which every submarine is embedded.
3. Human. It is the task of every submarine to develop the crew for future positions of higher responsibility. This is essential to sustaining the future war fighting capability of the Submarine Force. This dimension co-exists with the technology dimension within the administrative chain of command.

Operational Dimension

Recursion Level 1 – The Viable Submarine System in Focus. Simply put, this research adopts the *a priori* assumption that the purpose of the information architecture is indistinguishable from the purpose of the system that the architecture serves. We think of the information architecture as the nerves which govern the flow of information and the decision making functions embedded within the viable system. The purpose of the information architecture and the viable system it serves is to produce the output that the system is designed to produce. In VSM terms, the submarine is the “System-in-Focus” (Beer, 1985) or Recursion Level 1 in the operational dimension. The question remains, what output is the submarine system required to produce in the operational dimension?

In the operational dimension, there are two ways to look at the purpose of submarines. First, we might look at what the U.S. Navy “defines” submarines do. Second, we might look at what submarines actually do. This analysis begins with what the U.S. Navy says, relying on the need for the U.S. Navy to communicate the need (purpose) for submarines to Congress in order to justify their procurement. A deeper analysis of this question could be addressed by analyzing classified data that categorizes what missions (outputs) submarines are tasked, however, this approach does not seem warranted at this point.

The Congressional Research Service (O’Rourke, 2012) lists the following missions for U.S. Navy Attack Submarines (SSNs):

- Covert Intelligence, Surveillance, and Reconnaissance
- Covert Insertion and Recovery of Special Operations Forces
- Covert Strikes Against Land Targets
- Covert Mine Warfare (Offensive and Defensive)
- Anti-Submarine Warfare
- Anti-Surface Ship Warfare

O’Rourke’s discussion of the projected SSN shortfall² also highlights a day-to-day requirement for deployed U.S. Submarines. This is interpreted as a demand for U.S. Submarines to produce the latent capability to execute the above missions in prescribed locations at a prescribed rate (missions/unit time). In other words, there is an implied operational requirement for sufficient U.S. Submarines to be ready to produce some

² A decrease in U.S. Attack Submarines to less than 48 Attack submarines between the years 2022 and 2034.

portion of the above missions for a set period of time throughout the world. This research defines the submarine's ability to execute a specified action at a given time and place as submarine "presence."

SSGNs and SSBNs have slightly different mission sets and are not specifically analyzed in this research but it is expected that where the output is the same, the demands of the Viable Submarine System are similar.

For the purpose of this modeling, the above submarine missions are consolidated into three broad categories:

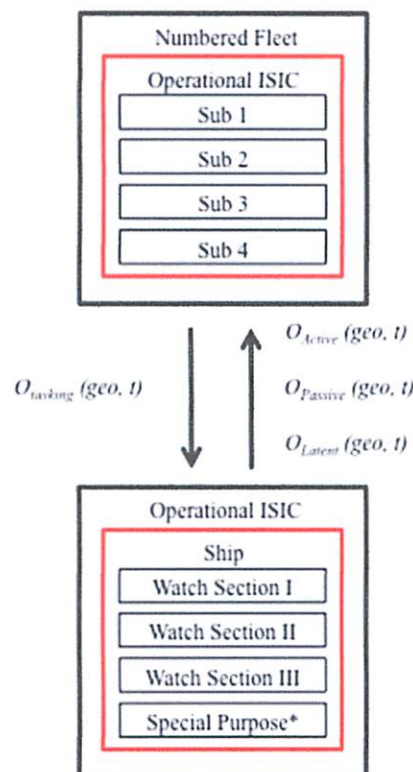
1. An SSN may be tasked to collect information for use by other naval organizations as directed by the operational commander. This may be a primary function such as in the execution of Intelligence, Surveillance, and Reconnaissance missions or a secondary function of another mission. The output consists of data collected over a specified geographic area and time and is communicated in whatever form required by the mission tasking. We label this passive collection of information over a given area and time in the operational dimension as the passive presence of the submarine, $O_{Passive}(geo, t)$, at a specified place (geo) and time (t).
2. An SSN interacts with its environment in both kinetic and non-kinetic ways. Torpedo attacks, missile launches, and deployment of unmanned vehicles are all examples of various kinetic and non-kinetic actions between the submarine and the environment. These are grouped together because they cause the submarine to interact directly with the environment in some way to create an effect. As in the monitoring presence, these actions are specified over a geographic area and time. We label this output of action over a given area and time in the operational dimension as the active presence of the submarine, $O_{Active}(geo, t)$.
3. As mentioned above, submarines are expected to routinely deploy in order to generate the latent capacity for executing any required mission over a specified geographic area and time. This requires the SSN to generate what the U.S. Navy calls "readiness", the capacity to exercise both mobility and missions across geographic space and time. We categorize this latent capacity for action in the operational dimension as the latent presence of the submarine, $O_{Latent}(geo, t)$. As a result, SSNs can produce a latent presence even while executing a tasked passive or active presence.

A key distinction between active presence and latent presence is the role of tasking. For example, if an SSN is tasked to be in a certain place and time to conduct a strike mission, then it is producing an active presence. If it has the ability to be in a certain place and time to execute a strike mission but has not been tasked, then it is producing a latent presence. Interestingly, this means that an SSN continues to produce a latent presence even when in port. A submarine's latent presence is roughly equivalent to its Status of Resources and Training System or SORTS rating.

Finally, the tasking of submarine always includes a requirement to report back on the status of tasking. The communication of operational status is essential for sustaining operational viability throughout the operational dimension. However, status reports are not a separate output; they represent communications between systems levels.

Recursion Level 2 – Producing the Stated Purpose. Submarines are tasked to produce their output continuously for weeks and even months at a time. The subsystems that produce this continuous output are identified as Recursion Level 2 (and will be later identified as subsystems of the Viable Submarine System). For the submarine, Recursion Level 2 is the watch section. During normal underway steaming, the submarine maintains three rotating watches. The submarine establishes special watch bills for special circumstances, such as getting underway, where most of the crew is employed for a limited time. There is always a watch section on duty when the submarine is underway.

Recursion Level 0 – The Next Higher Viable System. Looking at who tasks the submarine and receives the submarine's outputs identifies the next higher viable system. In the U.S. Navy, the tasking of ships and submarines follows the operational chain of command. For submarines at sea, this is the Operational Immediate Superior in Command (ISIC). A submarine's Operational ISIC may change, but a submarine at sea always has an Operational ISIC assigned - usually a theater ASW commander or strike group ASW commander. Figure 3 illustrates the levels of recursion above and below an SSN in the U.S. Navy³.



**FIGURE 3. Viable Submarine System Recursions (Operational Dimension)
Technology Dimension**

³ The special purpose* watch section represents special watch section details such as the maneuvering watch, battle stations, etc.

Recursion Level 1 – The Viable Submarine System in Focus. The technology dimension contains a hierarchy of systems that produce effects on the submarine's technology or infrastructure. Defining the submarine's infrastructure as external to the submarine technology dimension is a subtle but important point to appreciate. In the operational dimension, we are used to adapting to a changing environment. For example, when a storm appears on the horizon, we alter our course of planned operations. Similarly, in the technology dimension, we alter our planned activities when a piece of equipment breaks to adapt to the broken equipment. Also, note that there is an interaction between the technical and operational dimension. The failure of a piece of equipment may require a change in operational capability.

This concept of the technical dimension as a recursive system acting on the ship also extends to the changing infrastructure of the ship over time. No submarine completes its life with the same technology with which it started. Equipment is upgraded or removed as time progresses. Managing the changing infrastructure of the ship over time is a task executed in the technology dimension.

The U.S. Navy refers to the sustainment of submarine technology as maintenance. The purpose of the submarine's maintenance activities is defined in OPNAVINST 4700.7L, Maintenance Policy for U.S. Ships:

“U.S. Navy ships will be maintained:

- (1) In the highest practical level of material readiness to meet required operational availability (A_0) needs while minimizing total life cycle cost over the design life of the ship.
- (2) In a safe material condition.
- (3) Following shipboard habitability standards of OPNAVINST 9640.1A.
- (4) To meet governing environmental standards.
- (5) At the maintenance level that can best ensure proper accomplishment, taking into consideration applicable laws, urgency, priority, crew impact, capability, capacity, and total cost.”

OPNAVINST 4700.7L assigns the following responsibilities to individual ship COs:

“The ship's CO is responsible for the proper self-assessment, preservation, repair, maintenance, and operation of the ship, and for cost effective management of required maintenance actions. The ship's CO shall:

- a. Ensure ship's force accomplishment of organizational- level maintenance actions.

- b. Ensure that quality maintenance is performed by other activities by providing assistance and oversight, as necessary, to ensure that published quality assurance standards are adhered to per reference (a).
- c. Ensure documentation of all maintenance actions per reference (e), whether accomplished by ship's force or by other activities.
- d. Ensure the CSMP⁴ is maintained in a complete and up-to- date status.”

The first responsibility for the submarine is to accomplish the maintenance actions assigned. These maintenance actions are planned by the crew for each ship component⁵ to be accomplished at specified times. The intended output of these actions is to sustain or improve the reliability of ship components over the life of the ship. We label this output of availability ($T_{Availability}$) for a given component (*comp*) and time (*t*) in the technology dimension as the component availability of the submarine, $T_{Availability}(comp, t)$.

The second responsibility of the submarine is to monitor the quality of the work performed by outside organizations to ensure that it meets Submarine Force standards. The output of these actions are to constrain the variety of maintenance to ensure that only authorized methods are employed and that the results are acceptable to support submarine operations. In this role, the ship acts as an agent of the Submarine Force, monitoring the quality of maintenance actions performed on the submarine and providing information to superiors in the maintenance dimension. While not explicitly mentioned in the U.S. Navy Maintenance Policy above, the submarine also has the responsibility to monitor the quality of the crew's own work (U.S. Fleet Forces Command, 2011). We label this output as quality assurance (T_{QA}) for a given component (*comp*) and time (*t*) as the quality assurance output of the submarine, $T_{QA}(comp, t)$.

The third and fourth responsibilities of the submarine are to ensure that the maintenance status of the ship is reported to superiors in the maintenance dimension. This is the same status discussion that was described earlier in the operational dimension with different content. Providing status is not a separate output but instead a requirement of all system tasking. Figure 4 shows the levels of recursion in the technology dimension.

⁴ The CSMP stands for Current Ship Management Project. The CSMP documents the material status of the ship.

⁵ We use the term “component” to avoid the use of the more common phrase “ship system”, so as not to confuse the reader with the system concepts we are discussing.

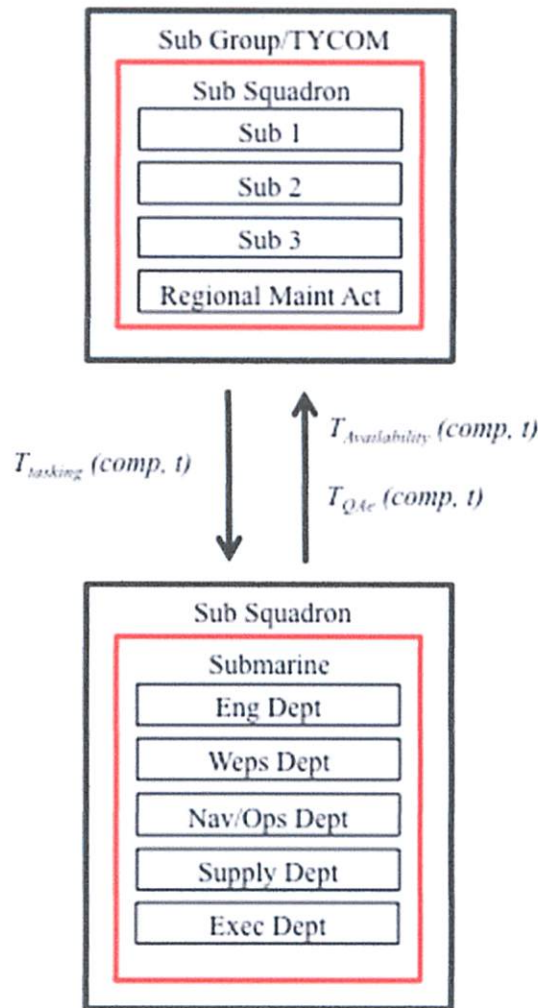


FIGURE 4. Viable Submarine System Recursions (Technology Dimension)

Human Dimension

Recursion Level 1 – The Viable Submarine System in Focus. The human dimension is the most difficult to characterize. It represents a hierarchy of systems that manages the complexity of the submarine’s crew. The human dimension must create the ability for the crew to execute its responsibilities in the technical and operational dimensions. The human dimension must also produce a steady stream of submariners that can sustain the outputs needed in both the technical and operational dimensions indefinitely over the entire timeline of submarine operations into the future.

The U.S. Navy assigns the following responsibilities to COs of all ships and submarines. In U.S. Navy Regulations, Article 0820 Welfare of Personnel:

“The Commanding Officer shall:

- a. Use all proper means to foster high morale, and to develop and strengthen the moral and spiritual well-being of the personnel under his or her command, and ensure that chaplains are provided the necessary logistic support for carrying out the command's religious programs to provide maximum opportunity for the free exercise of religion by members of the naval service;
- b. Maintain a satisfactory state of health and physical fitness of the personnel under his or her command;
- c. Afford an opportunity, with reasonable restrictions as to time and place, for the personnel under his or her command to make requests, reports or statements to the commanding officer, and shall ensure that they understand the procedures for making such requests, reports or statements;
- d. Ensure that noteworthy performances of duty of personnel under his or her command receive timely and appropriate recognition and that suitable notations are entered in the official records of the individuals; and
- e. Ensure that timely advancement in rating of enlisted persons is effected in accordance with existing instructions. ”

Additionally, In U.S. Navy Regulations, Article 0821 Training and Education:

“The commanding officer shall:

- a. Endeavor to increase the specialized and general professional knowledge of the personnel under his or her command by the frequent conduct of drills, classes and instruction, and by the utilization of appropriate fleet and service schools,
- b. Encourage and provide assistance and facilities to the personnel under his or her command who seek to further their education in professional or other subjects;
- c. Afford frequent opportunities to the executive officer, and to other officers of the ship as practicable, to improve their skill in ship handling,
- d. Require those lieutenants (junior grade) and first lieutenants who have less than two years commissioned or warrant service, and all ensigns and second lieutenants:
 - (1) To comply with the provisions prescribed for their instruction by the Chief of Naval Operations, the

Commandant of the Marine Corps, or other appropriate authorities; and

- (2) To receive appropriate practical instruction, as the commanding officer deems advisable, and to be detailed to as many duties successively as may be practicable.
- e. When practicable, designate a senior officer or officers to act as advisors to junior officers. These senior officers shall assist junior officers to a proper understanding of their responsibilities and duties, and shall endeavor to cultivate in them officer-like qualities, a sense of loyalty and honor, and an appreciation of naval customs and professional ethics.”

Many of the above listed responsibilities are instructions for the leadership and management of the crew, not requirements for outputs. Instructions to care for the physical, mental and moral well-being of the crew are intended to husband and sustain the physical and emotional resources of the crew.

The first set of outputs assigned to the CO, is the need to manage the professional development of members of the crew. In fact, most of the above responsibilities require COs to care for the professional development of their crews. Recording the performance of duty in service records, providing for advancement exams, and ensuring junior officers comply with their prescribed curriculum of instruction are required for the U.S. Navy to develop and manage a professional corps of sailors. These reports are used by higher echelon personnel commands to promote members of the service with the most potential for future service and to select personnel for assignments throughout their career. We label this output of Professional Development ($H_{Prof Dev}$) for a given crew member (*member*) and time (*t*) as the professional development of the submarine crew, $H_{Prof Dev}(\text{member}, t)$.

The next two outputs are not made clear in the above listed responsibilities but are known to the authors from their own experience as submarine officers. The CO is responsible for ensuring that the crew is trained in the execution of their maintenance and operational responsibilities. Crew capabilities are developed through a wide range of service schools, on-board instruction, and team exercises. The effectiveness of this training is monitored by higher echelon commands by periodic formal and informal inspections. We label the output of technical ability to maintain the ship ($H_{Technology}$) for a given component (*comp*), crew member (*member*) and time (*t*) as the technical ability of the submarine crew, $H_{Technology}(\text{comp}, \text{member}, t)$. The output of operational ability to operate the ship ($H_{Operations}$) for a given mission (*mission*), crew member (*member*) and time (*t*) as the operational ability of the submarine crew, $H_{Operations}(\text{mission}, \text{member}, t)$. Figure 5 shows the levels of recursion in the human dimension.

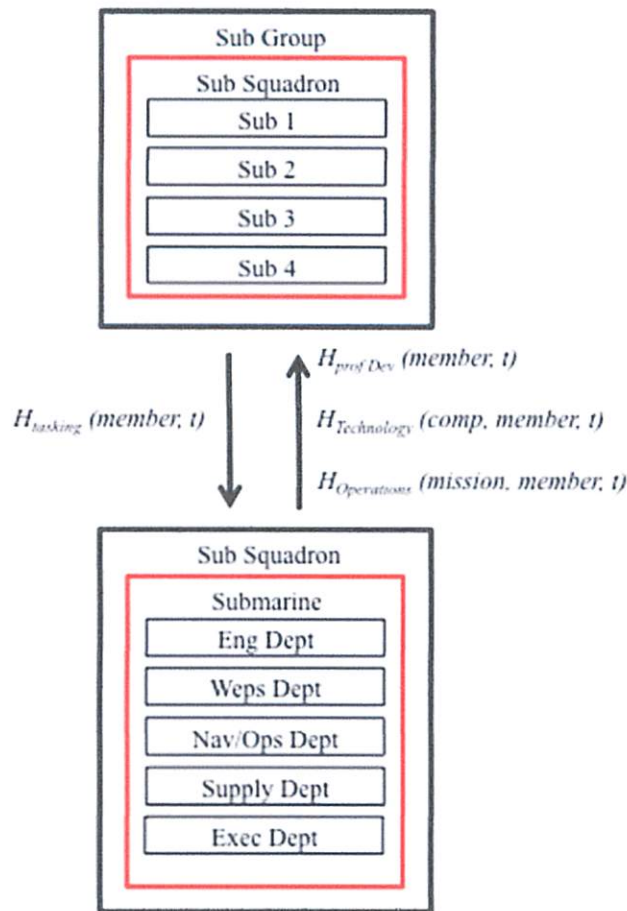


FIGURE 5. Viable Submarine System Recursions (Human Dimension)

Systems Dimensional Landscape

The submarine system does not have the luxury of responding to one dimension at a time. All three dimensions make demands on the submarine, each with their own urgency and deadlines. When in a maintenance availability, the technology dimension is most urgent and bears most directly on future ship's operations. When deployed, the operational dimension is most urgent. Unfortunately, there is rarely a time when the human dimension becomes urgent. As a result, it is often up to the individual submarine to emphasize human development and training tasks.

The interaction of these three dimensions creates a systems landscape within which the submarine as a viable system exists. In order to model the information and decision flows within the viable system, we must choose one dominant dimension and system for focus. This analysis chooses the operational dimension of the Viable Submarine System as the System-in-Focus. As stated before, all models are incomplete representations of the world in which we exist. It bears repeating that models are not right or wrong, they are either useful or not. Figure 6 shows the dimensional landscape within which the Viable Submarine System exists.

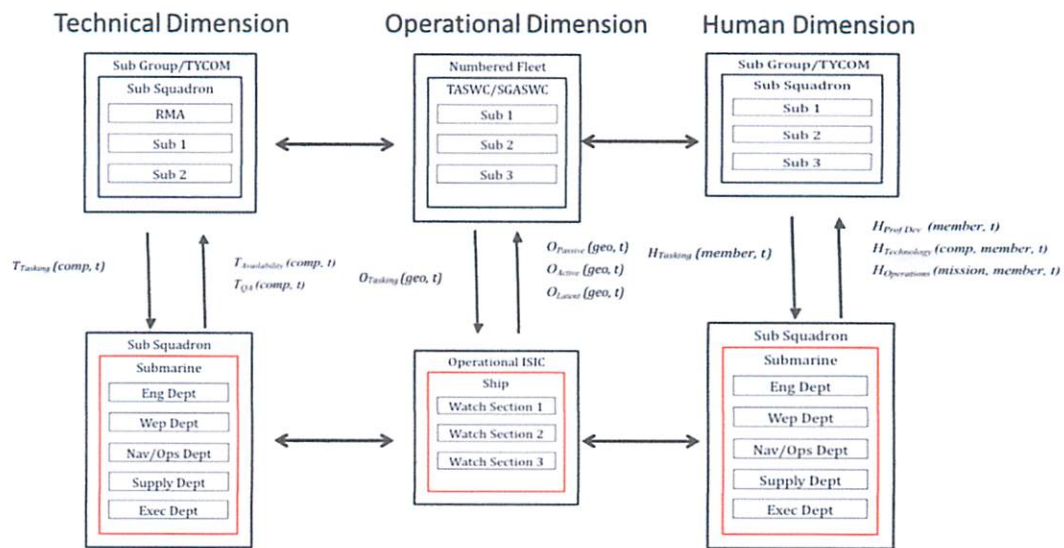


FIGURE 6. Submarine System Dimensional Landscape

Viable Submarine System Summary

1. Is a submarine a viable system? If it is, then what defines the Viable Submarine System and what is the role of information and decision making within the Viable Submarine System?

A submarine is a viable system in the sense that it is an organization designed for the purpose of adapting to a changing environment and sustaining itself while producing needed outputs within a nested hierarchy of systems. It remains viable only so long as essential elements of the system are maintained within allowable physiological limits (See Homeostasis Principle in Skyttner, 2005).

Information is what flows throughout the Viable Submarine System and enables the system to make the decisions necessary to sustain its output in continually changing circumstances. It is fundamental to the control features of the viable system.

a. What is the purpose of the Viable Submarine System? The Viable Submarine System produces outputs in three dimensions.

1) Operational

- 1) $O_{Passive}(geo, t)$, Passive Operational Presence at a Given Place and Time.
- 2) $O_{Active}(geo, t)$, Active Operational Presence at a Given Place and Time.
- 3) $O_{Latent}(geo, t)$, Latent Operational Presence at a Given Place and Time.

2) Technological

- 4) $T_{Availability}(comp, t)$, Availability of Technology for a Given Component and Time.
- 5) $T_{QA}(comp, t)$, Quality Assurance for Other Organizations Providing Technological Availability for a Given Component and Time.

3) Human

- 6) $H_{ProfDev}(member, t)$ Professional Skills of Crew Members over Time.
- 7) $H_{Technology}(comp, member, t)$, Technical Skills of Crew Members for a Given Component and Time.

8) $H_{Operations}(mission, member, t)$, Operational Skills of Crew Members for a Given Mission and Time.

- b. Recursion level 1 - What is the relevant viable system that meets the stated purpose? This is the System-in-Focus.** The submarine and its crew are the System-in-Focus.
- c. Recursion level 2 – What are the subsystems within the viable System-in-Focus that produce the stated purpose? This is the nucleus of the System-in-Focus.** In the operational dimension, the submarine watch sections are the subsystems that produce the operational output of the submarine. In the technological and human dimensions, the submarine administrative departments as lead by their department heads are the subsystems that produce the technological and human outputs of the submarine.
- d. Recursion level 0 – What is the next higher-level viable system in which the System-in-Focus is embedded?** In the operational dimension, the submarine is assigned an operational ISIC. This is typically a Theater ASW Commander or Strike Group ASW Commander when the submarine is at sea. In the technological and human dimensions, the submarine is assigned an administrative ISIC. This is typically a Submarine Squadron.

Viable Submarine Watch Section Subsystem

In the next several sections, we dissect the VIRGINIA Block III Submarine according to the structure and rules of the viable system model. On the one hand, the nested hierarchies of viable systems that represent the Submarine Force have achieved tremendous success and demonstrated impressive viability over many decades. Submarine crews with sophisticated undersea technology consistently produce outstanding results in the most demanding environments. On the other hand, the science of viable systems presents a normative model that has proven effective over many decades of use in organizational research. Comparison of a submarine organizational model and the VSM yields insights into how the submarine system might be strengthened and where the Viable System Model may need to be improved.

Our System-in-Focus for this research is in the operational dimension. Our research is motivated by a desire to develop a systems based methodology for assessing technological changes to the VIRGINIA Block III submarine design.

VIRGINIA Block III Watch Sections

The VIRGINIA Class Submarine is designed for an underway complement of 14 officers and 104 enlisted (Hamburger et al., 2010). There are substantial differences in VIRGINIA Class technology when compared with earlier submarine designs. The VIRGINIA Class has a fly-by-wire Ship Control System operated by a Pilot and Co-Pilot who replaced the Helmsman, Planesman, Chief of the Watch and Diving Officer watch standers of earlier submarine designs. Sonar watch standers have been relocated to the Control Room, which is now larger since it no longer has a periscope. The Block III Variant of the VIRGINIA Class submarine incorporated design changes that helped to reduce the overall cost of VIRGINIA submarine construction ("Virginia Block III: The Revised Bow," 2008). Block III changes include a redesigned bow incorporating two payload tubes that each house six Tomahawk missiles, a redesigned sonar suite that uses a Large Aperture Bow array instead of a sonar sphere and 25 other design changes.

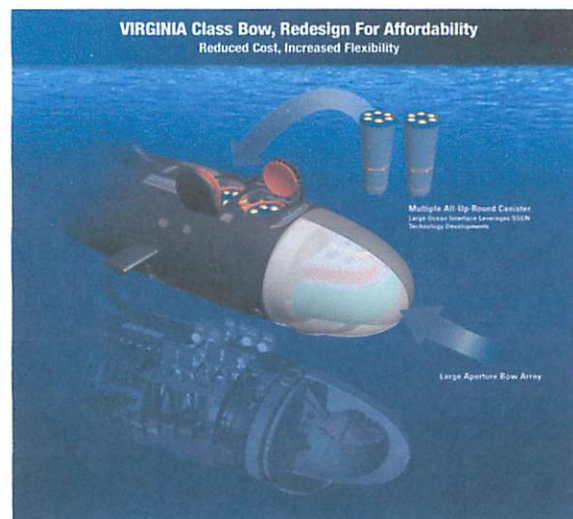


FIGURE 7. Graphic from “Virginia Block III: The Revised Bow” (2008)

While VIRGINIA Class submarines contain a remarkable number of technological innovations, the primary viable subsystems in the Operational Dimension remain the same regardless of submarine class. The submarine crew is divided into three underway watch sections with one on watch at all times. The three underway watch sections are designed to handle the majority of operational conditions and can be sustained nearly indefinitely. Occasionally, a special purpose watch bill is employed such as when the Maneuvering Watch is set while navigating out of port. These special purpose watch bills are designed for specific situations but, as a result, can only be maintain for limited times because they employ large numbers of the crew. Of course, there are many variations possible between the standard three section watch bill and typical special purpose watch bills that increase the operational variety that watch sections can generate.

In the VSM, a viable subsystem⁶ is an operational and C2 element interacting with the environment (see Figure 8). The interactions are intended to produce some portion of the Viable Submarine System's required outputs. In the case of standard underway watch sections, they are typically responsible for sustaining outputs in 6-hour intervals. We have described how the Submarine is required to produce three outputs in the operational dimension. Each of these outputs is examined from a watch section perspective with the following results.

When the ship is tasked to produce an operational output like passive presence, it develops a plan for achieving the presence tasked in both time and place and divides up responsibility for execution of the plan to the watch sections. Each watch section is responsible for executing a 6-hour segment of the plan in rotating order. The three components of the watch section are organized as shown in Figure 8. Members of the

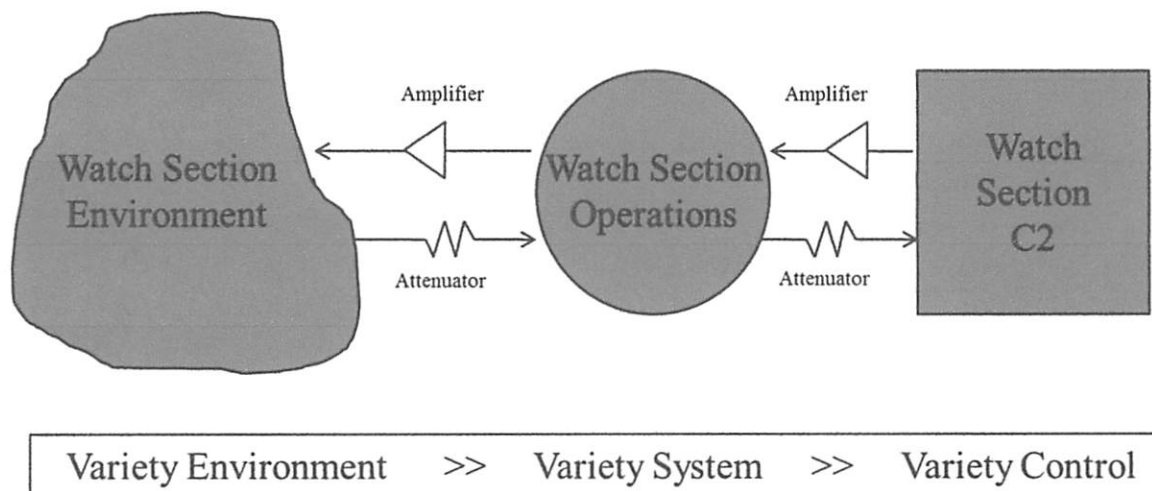


FIGURE 8. Submarine Subsystem (Operational Dimension) – Watch Section
(Adapted from (Espejo, 1989))

⁶ Usually called System One in VSM literature. We use common submarine phraseology here. What we lose in academic accuracy we gain in overall comprehension for our intended readers.

watch section are performing C2 functions when they review the requirements of the watch, develop a plan, and communicate it throughout the watch section. Members of the watch section are executing operational functions when they operate the ship, perceive various inputs from the environment and execute the plan. During execution, watch section members monitor the results of the watch section's operations and provide feedback to other members of the watch section as necessary.

The key here is to separate the people in this scenario from the functions they perform. This viable system model is diagramming information flow and decision making within the submarine system. As a result, our model's diagrams represent functions, not people.

The environment of the watch section has near infinite variety in the number of different states it might produce. A VIRGINIA Block III submarine operates in an undersea environment bounded by shallow or coastal water and bottom topological features. Environmental factors such as, temperature, salinity, current, fronts, eddies, and weather affect the submarine's ability to travel from point to point at desired depths. The environment also contains other vessels that the submarine must avoid or who might detect its presence, either accidentally or deliberately. Finally, the submarine is a warship and must be able to detect and evade potential adversaries and weapons employed against it.

The watch section "senses" the effects of the environment through one of three paths. First, effects are communicated through the physical hull of the ship. If the submarine travels into a body of water with low salinity, the ship will lose buoyancy and the submarine watch section will need to compensate to maintain ordered depth. In effect, the submarine physical structure acts as a highly efficient variety attenuator and transducer. It is an attenuator because the highly variable environment is reduced to a small number of physical signals such as pitch, yaw, and acceleration in the x, y, and z axes. It is a transducer because the signals of wave action and salinity are converted into the physical signals just mentioned.

The watch section also senses the environment through the submarine's various sensors. Information is communicated to them by the submarine's acoustic, electromagnetic, and other sensors. Each sensor filters and reduces the variety of the information to a level that can be understood by the members of the watch section. For example, a large variety of acoustic energy impinges the submarine's acoustic sensors every minute. Some of this acoustic energy is filtered by the process of transduction because it is outside of the sensor's frequency limits or it is too weak to be processed. Of the information that is processed, the operator views it on the ship's acoustic equipment and it is interpreted as biologics (living organisms), surface ships, or submarines. The ship might be surrounded with acoustic energy but the watch section might say there is nothing around, because the variety of the information has been reduced to relevant information about ships and submarines. This filtering and reduction in variety so that the submarine can sense the relevant information and take the necessary actions to succeed is the primary role of the watch section.

The watch section receives a third category of information through channels of human communication. Most of this information is funneled through official channels to the ship. The watch section receives this information and filters out all but operationally

Watch Section Environment		Watch Section Operations
High Variety Input	Transducer	Low Variety Input
Bottom Topography	Submarine Hull	Motion in X Direction
Coastlines		Motion in Y Direction
Temperature		
Salinity		Motion in Z Direction
Currents		
Fronts and Eddies		Pitch
Weather, Sea State		
Other Vessels		Roll
Those Who Might Detect the Submarine		
Weapons		Yaw
Energy Sources	Sensors	Multiple Sensor Inputs
Communications	Radio Receiver	Submarine Messages
Watch Section Environment		Watch Section Operations
High Variety Input	Transducer	Low Variety Output
Covert Presence Anywhere in the World	Rudder	Multiple Auxiliary States
	Propulsor	Multiple Propulsion States
	Control Surfaces	Multiple Ship Control States
Stealth	Hull	Multiple States of Quietness
Intelligence on Demand	Radio Transmitter	Radio System States
Damage inflicted on Land and at Sea	Weapons	Weapon System States

TABLE 1. The Transduction of Variety between the Watch Section's Environment and Watch Section Operations

relevant information. The rest is forwarded on to be handled by administrative functions of the crew.

The operations of the watch section produces an output, which when combined with the outputs of its fellow watch sections, produces the output required of the submarine as a viable system. Watch section operations produce a course, speed and depth vector through the environment. Watch section operations also produce some measure of detectability or stealth. These features amplify the variety of the submarine by enabling the submarine to travel all over the world and operate in challenging environments with great operational freedom (See Table 1).

C2 functions within the watch section have significantly less variety than watch section operations functions. As a result, C2 functions also need attenuators and amplifiers to balance variety with operations (See Table 2). The primary attenuators and amplifiers of watch section C2 are Standardized Procedures and Communications Doctrine that allows watch section command to give a single order and control complex synchronized watch section operations. Many of the internal submarine components are managed by exception – not unlike the human autonomous nervous system. This reserves the primary

conscious focus of watch section C2 functions for the dynamic environment outside the ship.

Watch Section Operations		Watch Section C2
Variety	Transducer	Effect
Multiple Auxiliary States	Standard Reports	Management of Majority Plan by Exception
Multiple Propulsion States		
Multiple Ship Control States		
Multiple States of Quietness	Reports of Exceptions (Equipment Failures, Etc)	Reserve Primary Focus for Management of Dynamic External Situations
Radio System States		
Weapon System States		
Watch Section Operations		Watch Section C2
Effect	Transducer	Variety
Control of Auxiliary States	Standardized Procedures	Multiple Control Watch Station Modes
Control of Propulsions States		
Control of Ship Control States	Standardized Orders	
Control of Quietness States		
Control of Radio States	WS Briefings	
Control of Weapon System States		

TABLE 2. The Transduction of Variety between the Watch Section Operations and Watch Section C2

Beer (1985) provides three principles of organization for analysis. The following paragraphs will consider the watch section as a viable sub system from the perspective of Beer's principles:

- **The First Principle of Organization.** Managerial, operational, and environmental varieties, diffusing through an institutional system, tend to equate; they should be designed to do so with minimal damage to people and cost.
- **The Second Principle of Organization.** The four directional channels carrying information between the management unit, the operation, and the environment must each have a higher capacity to transmit a given amount of information relevant to variety selection in a given time that the originating subsystem has to generate it in that time.
- **The Third Principle of Organization.** Wherever the information carried on a channel capable of distinguishing a given variety crosses a boundary, it undergoes transduction; the variety of the transducer must be at least equivalent to the variety of the channel.

Beer's first principle of organization states that variety will achieve equilibrium. In a well-functioning system, the system organization absorbs much of the variety and very little is left as residual variety. Remember, variety is a measure of the number of states that each part of the system can adopt. While it is practically impossible to count the number of states that the watch section environment, operations, and C2 can adopt, we can practically assess how the balance is achieved. The key question in the balance between the environment and operations is whether the watch section has the ability to adapt itself into enough different modes of operations in order to deal with the multitude of environmental challenges it receives. For example, whether operating in equatorial waters or under the arctic ice, does it have modes of operations that allow it to do so? Relying upon the fact that U.S. submarine operations are both complex and largely successful, we submit that the answer is that Beer's first principle is largely satisfied. The VIRGINIA Class Block III Submarine watch section has sufficient operational and C2 variety as a subsystem. Note: We are not looking inside System One at the inner workings of the watch section. For example, how well does the VIRGINIA Class submarine crew manage the multitude of display screens in the VIRGINIA Control Room? If we did, we might draw different conclusions. This analysis is being conducted with the Submarine as the System-in-Focus that limits our focus to one level down in the viable system recursion.

Beer's second principle of organization is more of a challenge to the VIRGINIA Class watch section. The VIRGINIA Class submarine has more sensors than any other U.S. submarine class. As a result, more information flows from the watch section environment into watch section operations (the ship) and watch section C2 (the VIRGINIA Control Room) every second than on previous submarine classes. This strains the ability of VIRGINIA Class watch section C2 more than previous U.S. submarine classes and increases the potential of situations where higher information flow is generated than can be absorbed. If it is not absorbed, then it is functionally discarded because watch section C2 must continue to process the next batch of incoming information. Of course, the ability to flow more information does not mean that more information is flowing in every situation. In cases of no or few contacts being "sensed", there will be relatively little information flowing from the watch section environment through to watch section C2. However, in environments with high contact density, the amount of information flowing is near its peak. The likelihood of ignoring or discarding information is higher. This increased information flow through the VIRGINIA watch sections has implications for sensor development. As the sensors for submarines improve, the amount of information that can be generated for a given period of time increases geometrically⁷. This further strains the VIRGINIA Class submarine relative to other U.S. submarine classes during periods of high information flow.

Beer's third principle examines how information is changed as it flows through the system. In the VIRGINIA Class submarine watch section, the same strains felt in information flow are felt in the transformation of information. This is because, as in the case of information flow, the VIRGINIA Class watch section relies upon watch section C2 functions (control room personnel) to transform incoming sensors data into contact data. For any given vessel within range of the VIRGINIA's sensors, there may be

⁷ Assumes search volume of improved sensors expands within a cylindrical search volume.

multiple sonar sensor feeds, an optical sensor feed, and electronic sensor feeds which must be reduced by the watch section into a single estimate of contact position. Again, the VIRGINIA Class watch section's ability to transduce information will be most strained during periods of high information flow.

The next topic to consider is how the VIRGINIA Viable System limits the authority of each watch section. In the area of Navigation, the watch section is limited by approved navigation charts. Approved digital charts are an essential part of the planning that is performed by the ship for use by the watch sections. Each chart provides the geographic boundaries within which the watch section must remain. The second source and limit of watch section authority are the ship's Commanding Officer's Standing Orders, Standard Operating Procedures, Submarine Force Organization and Regulations Manual, and other doctrinal materials which delineate the limits of authority for the Officer of the Deck and the Watch Section in general. Finally, there are the Commanding Officer's Night Orders which convey specific authorities or limits for the upcoming 24 hours.

These documents together should be regarded as an essential bargain struck between the VIRGINIA Viable System and the watch sections. The bargain defines the limits of autonomy and authority that each watch section can exercise. Of note, the majority of the bargain struck on a VIRGINIA Class Submarine is not unique to the VIRGINIA Class. Even the Commanding Officer's Standing Orders are established by the Submarine Type Commanders and distributed throughout the force. The VIRGINIA Class Block III Submarine has some unique components and equipment configurations that require the use of VIRGINIA unique procedures and these procedures are standardized across all VIRGINIA submarines. Given the establishment of so much Submarine Force doctrine in the defining of watch section tradeoffs between autonomy and restrictions, it is difficult for individual commanding officers to grant watch sections more autonomy. However, if the commanding officer feels it is necessary, the night orders may be used to spell out the limits of authority/restrictions for a specific event which is anticipated over the next 24 hours.

The VIRGINIA Class Viable System (and that of all U.S. Submarines) has one essential tool which dramatically increases the autonomy of watch sections when circumstances warrant – the Command Duty Officer (CDO). When the CDO is stationed, a command qualified officer is assigned as an adjunct to the watch section with the authority to authorize many operations reserved for the authority of the commanding officer. This effectively expands the authority of the watch section but this gain in authority is not without cost. The time spent by command qualified officers in assisting the watch sections makes it more difficult for the same command qualified officers to work together for the VIRGINIA Class Viable System as a whole.

Finally, we come to the topics of control, autonomy, accountability, and performance measurement. The system level control of the VIRGINIA Viable System is under the same variety constraints as the rest of the system in that it must match its variety to the subsystems it interacts with. VIRGINIA's control function has less variety than the combined variety of the individual watch section C2 elements. As a result, we again need attenuators and amplifiers to balance variety. The primary amplifiers of higher level management in a viable system are resource bargains and restraints or controls placed upon the watch section (Beer, 1985). The resource bargain is a bargain struck between

the submarine control function and each watch section C2. The submarine control function wants the watch sections to produce an output and must provide the necessary resources. Watch section C2 must agree to produce what is required in the manner required. In reality, the bargain in VIRGINIA is struck by the submarine control function estimating the capability of each watch section in relation to what is required. If the watch section is deemed not capable enough, additional resources may be provided. This resource bargain is documented and passed on to the watch section in the form of a plan. The manner in which the watch section achieves its output is also specified by the VIRGINIA control function. The rules for the conduct of the watch are embedded within Submarine Force doctrine as communicated by each individual ship's command element. These rules act as restraints on the variety of the watch sections while amplifying the orders of the VIRGINIA control function. For example, when the VIRGINIA control function wants to surface the ship, it does not need to give detailed orders to the watch section on how to surface the ship. It need only give a predetermined order. The watch section understands what the standard order means and puts the entire ship into action. At the same time, its variety is constrained to the extent that every member of the Watch Section understands that procedural compliance is required.

Each watch section is held accountable for the performance of the output of the VIRGINIA Viable System for six hours at a time. VIRGINIA's control function creates a plan and communicates this plan to the watch sections. Each watch section is then expected to execute its portion of the plan. This is a critical exercise in variety reduction. VIRGINIA's control function cannot possibly absorb all the information that is managed by the watch sections in even the most basic procedure. Instead, the VIRGINIA control function cares that the output desired by the plan is being achieved. As a result, measurement is performed in terms of the plan created. For navigation, performance is made by determining if the ship has moved the intended distance. For communications, performance is measured in terms of communications sent or received. The same goes for the other aspects of the plan. Figure 9 models the interactions between watch section C2 and VIRGINIA Viable System control function.

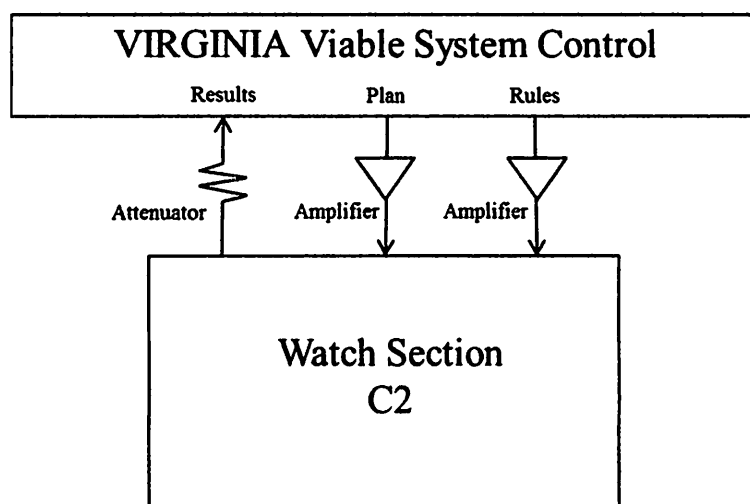


FIGURE 9. Variety Balance between the VIRGINIA Viable System and Watch SectionC2.

In order to execute the plans that it is responsible for, watch section C2 must regulate the operations under its authority. According to Beer (1985), there are two key methods that subsystems use to regulate its operations. First, the subsystem management ensures that sufficient channels of information are in place to contain the variety that operations will generate. Second, the subsystem employs strategies that offer requisite variety. We have already discussed the channels of variety flow earlier when we reviewed the three principle of organization. This section will review how the employment of strategies affects the submarine watch section.

General systems theory proposes a principle known as the Basins of Stability principle. It states, "Complex systems have basins of stability separated by thresholds of instability. A system dwelling on a ridge will suddenly return to the state in the basin" (Skyttner, 2005: 101). The watch section is a complex system that must act on numerous sensor inputs while guiding the VIRGINIA Viable System through a demanding and potentially deadly environment. If we consider the totality of the information being considered and potential options for action, the Watch Section cannot possibly consider them all. Instead, the Watch Section collectively employs methods that are either embedded in Submarine Force doctrine or which have proven to be successful for the watch section in the past. Collectively these predilections build up over time like a collective Kalman filter. Watch Section C2 gives greater weight to sensors and strategies that have worked in the past and little weight to other sensors and strategies. This becomes an effective filter for information and variety as long as the strategies are successful. These strategies become basins of stability for watch section behavior.

The Conant-Ashby Theorem states that every regulator must contain a model of the system it regulates (Beer, 1994). In the case of watch section C2, it must contain a model of the submarine within its environment. Much of this model is built upon information gathered and distributed as part of the submarine navigation plan. This model typically takes the form of approved digital charts with a required plan of intended movement and the Commanding Officer's Night orders. However, models of the vessels around the submarine must supplement the submarine navigation plan since the locations of vessels cannot be predicted ahead of time. This requires the watch section C2 team to collect information from the environment and construct models in real time. The purpose of these models is to compare where the submarine is to where the submarine should be and to enable watch section C2 to issue orders to ensure that watch section operations comply with the submarine navigation plan (See Figure 10.)

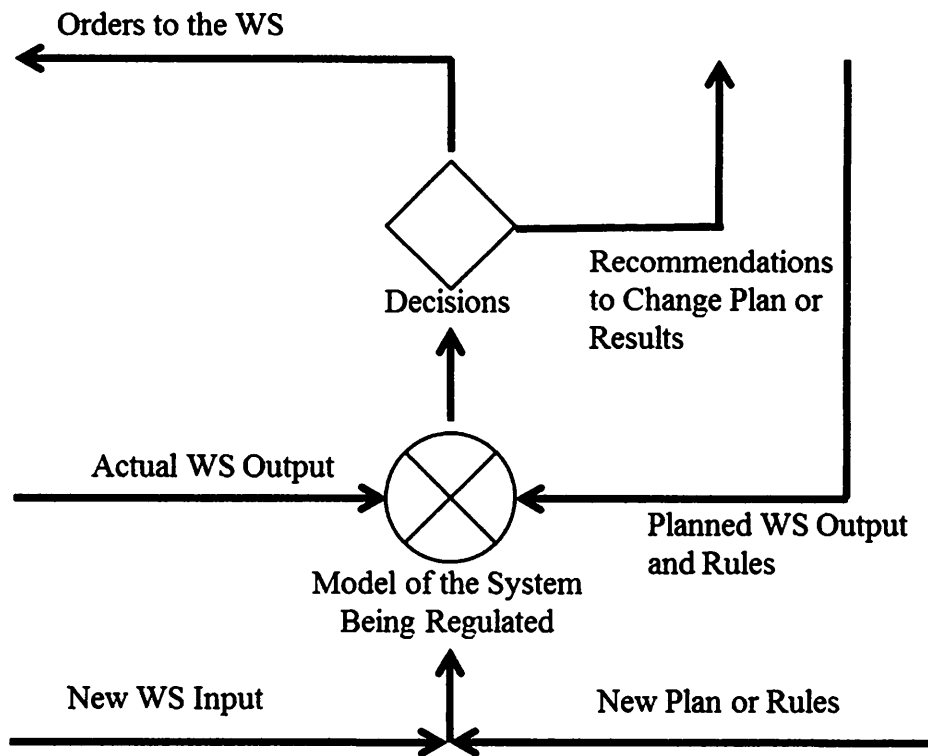


FIGURE 10. Essential Functions for Regulation of the System

We complete this section by constructing a model of the viable subsystems within the VIRGINIA Viable System. Typically there are three underway watch sections formed and various temporary watch bills such as the Maneuvering Watch that are available. We shall label the three watch sections as Watch Sections I, II, and III. The occasionally used special purpose watch sections will be added in a dotted box to show they are employed only when required.

The environments of Watch Sections I, II, and III are different but continuously connected. Imagine a situation where the VIRGINIA is in transit. During the first 6 hours, Watch Section I encounters an environment defined in time and space by the movement of the submarine on its watch. Watch Section II takes responsibility for the movement of the submarine through the environment as it relieves Watch Section I, and so on. Each watch section encounters a different environment and has a different part of the VIRGINIA Viable System output to produce. See Figure 11.

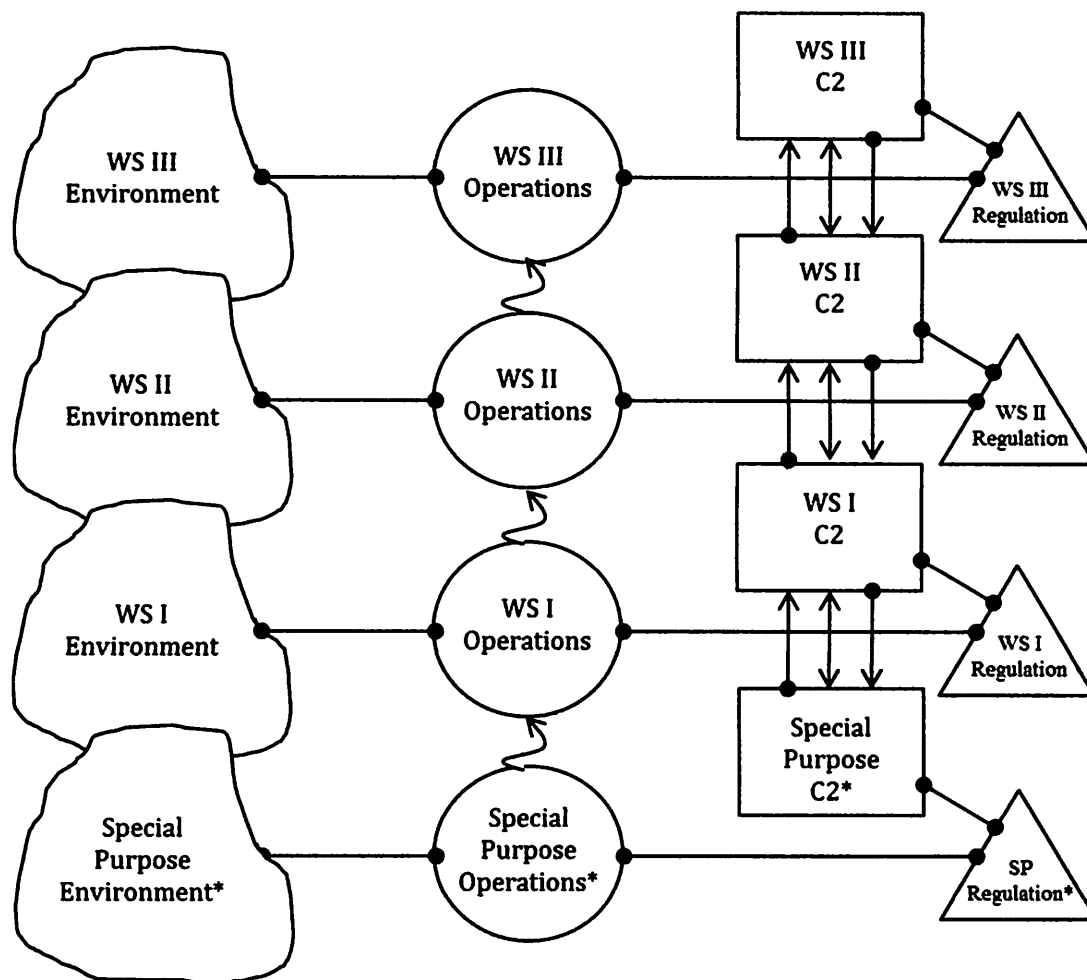


FIGURE 11. Subsystems of the VIRGINIA Viable System

Viable Submarine Watch Section Subsystem Summary

1. What are the viable subsystems within the VIRGINIA Block III Submarine?

In the operational dimension, the submarine watch sections are the viable subsystems that produce the operational outputs of the Viable Submarine System. At this level of recursion, the only difference between the watch sections of different submarine classes (and naval ships in general) is that the specific missions assigned will be relevant to the range of operational capabilities that the submarine system can achieve.

a. What are the relevant environment, operations, and C2 of each subsystem element?

The environment of the viable submarine watch section subsystem is all information received by the submarine during the time period that the watch section is on duty. In the geographic sense, the environment is bounded in time and space. In an information sense, the environment is bounded by communications and sensor signals received. In a ship and warfighting sense, the environment is bounded by the actions of other vessels, warships, sensors, and weapons that are sensed or believed to exist.

The operations of the viable submarine watch section subsystem are amplified by a relatively small set of transducers as it acts to adapt to its environment and produce its output. The watch section can choose its three-dimensional path by employing the submarine's control surfaces and mode of propulsion. The watch section can choose to communicate with the environment. The watch section can launch human or mechanical probes into the environment that range from SEAL warfighters and torpedoes to salinity and temperature probes. The greatest overall amplifier of a submarine's operations is its stealth. As long as human elements in the environment are unaware of its presence, the submarine is able to control the pace of its interactions with the environment.

The C2 element of the viable submarine watch section acts as the interface between higher level C2 and the watch section and oversees watch section operations. The C2 function creates a negative feedback loop that monitors the required output of the viable watch section subsystem and makes corrections to achieve the desired output over time. The regulation function supports C2 by comparing actual output data to the plan (desired output) requires a model of the viable watch section system interacting with its environment. The traditional model used by naval ships is the navigation chart.

b. What limits does higher authority place on each viable submarine watch section subsystem? Submarine Force doctrine is communicated by the Commanding Officer's Standing Orders, the procedures of the ship's systems manual, various naval warfare publications and other governing doctrine that prescribe rules for submarine watch section behavior. Collectively these represent a relatively stable set of rules for the watch section. Orders such as

Commanding Officer's Temporary Standing Orders, specific Operation or Exercise Orders communicate temporary rules. Overall, the purpose of these limits act to reduce the variety of viable submarine watch section behavior to within organizationally acceptable boundaries.

- c. **How is each Viable Submarine Watch Section Subsystem held accountable and how is performance measured?** The submarine watch sections are held accountable for the required outputs of the Viable Submarine System during their watch. The progress of the ship, the communications received and transmitted and the sensors and weapons employed by the watch section all combine to produce the output of the Viable Submarine System. The performance of the watch sections is measured against the tasking the submarine received from higher authority as communicated to the watch section in the form of a plan. The outputs that the watch sections are required to produce are typically communicated by and measured against the Commanding Officer's Night Orders and the submarine's approved plan of intended movement.
- d. **Diagram the Viable Submarine Watch Section Subsystems according to the Viable System Model rules.** See Figure 11.

Viable Submarine Watch Section Damping Functions

Stafford Beer's (1985:71) fourth principle of organization states, "The operation of the first three principles must be cyclically maintained through time without hiatus or lags". This principle states that from a cybernetic perspective, the individual sub system elements need help to prevent unintended oscillations that waste resources and reduce the overall output of the Viable System as a whole. The function of preventing oscillation is assigned to the watch section damping function⁸.

The concept of damping functions in VSM can be difficult to grasp. Usually there is no single person or office within organizations that are tasked with carrying out this function. To make matters worse, the activities of damping functions are often closely linked with the management of the Viable System as a whole. As a result, subsystems often confuse damping functions as Viable System autocracy. So the essential question remains, what is the difference between Viable System C2 and damping? Beer (1985) explains it this way. Viable systems work best when the individual subsystems are granted maximum autonomy. Unfortunately, the actions of one subsystem may unintentionally interfere with the actions of a second. This occurs because neither subsystem has sufficient organizational perspective to appreciate the functions of the system as a whole. This is certainly rings true for the VIRGINIA Viable System. Watch Section I might use its autonomy to linger during its transit collecting maximum information along the way. The submarine stays within its allowable geographic constraints but it is now behind track. This results in Watch Section II taking the watch with the need to speed up to maintain the overall intended movement of the ship. As a result, the submarine cycles between low and high speed transits. How should this be resolved? One way would be for the VIRGINIA Viable System to require Watch Sections to stay closer to the intended track of the ship. This would unnecessarily restrict the movement of the ship and the autonomy of the watch sections. The second would be to foster a culture within the watch sections to not overly constrain the relieving watch section without good reason. (In submarine crew parlance, this is known as "bagging" the oncoming watch.) The second solution is preferable because it maximizes individual watch section autonomy while providing sufficient damping to minimize oscillations between watch section outputs. This research has identified six damping functions within the VIRGINIA Viable System from our experience in submarine operations (See Figure 12):

1. **Standard Protocols.** The Watch Sections are required to generate routine written and oral reports to the VIRGINIA Viable System on daily basis.
2. **Timetables and Routines.** The Plan of the Day, the Plan of the Week, Commanding Officer's Standing Orders and other documents set a schedule for routine events so that they are not inadvertently bunched or spread out by Watch Section autonomy.
3. **Submarine Culture.** Submarine Culture is expressed on each ship as interpreted by the submarine's Commanding Officer and senior leaders. This effect, often

⁸ In traditional VSM terms the damping function is System Two.

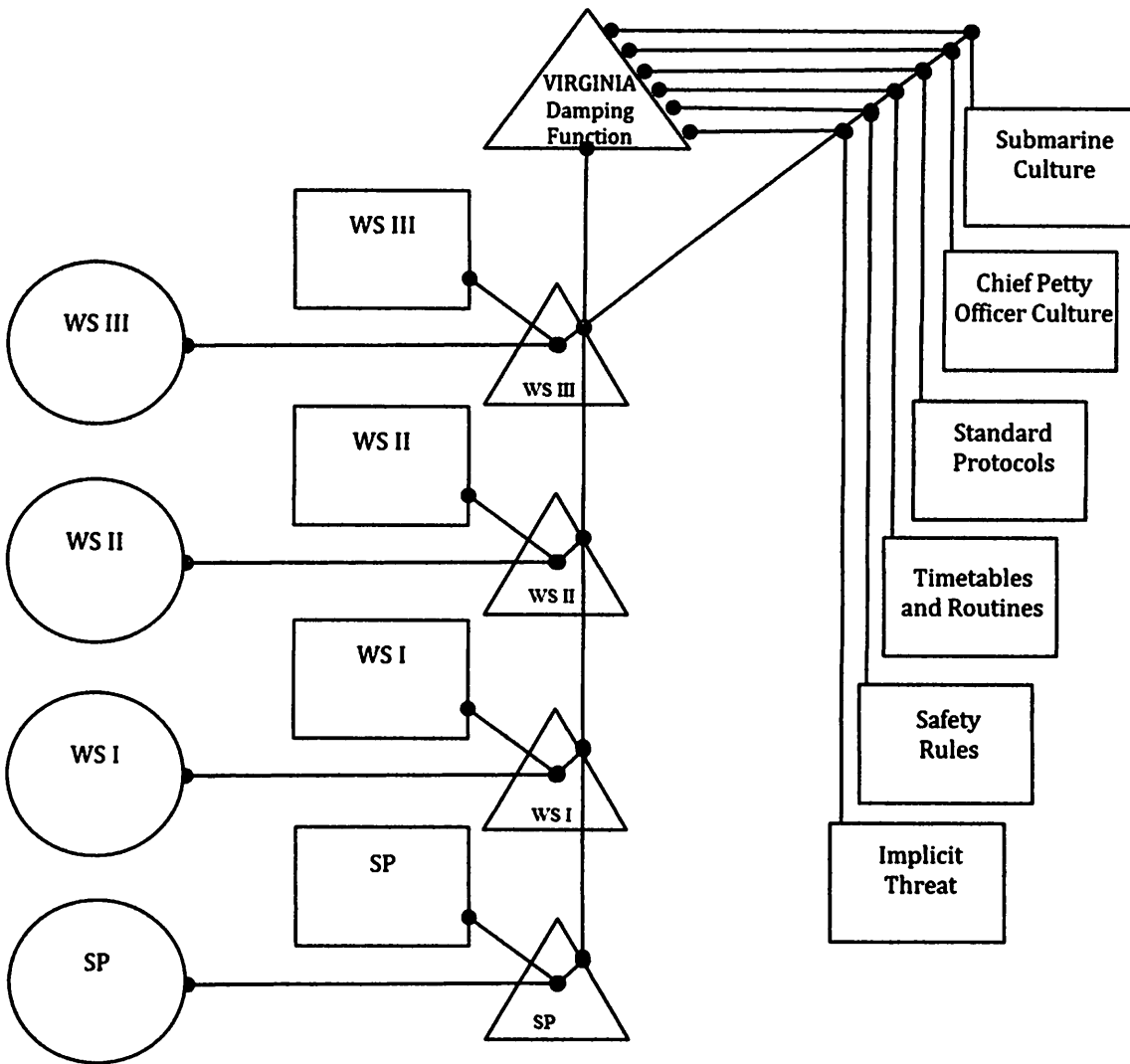


FIGURE 12. VIRGINIA Viable System Damping Functions

expressed as the ship's Command Climate, communicates expectations to the watch sections on how they work together and perform their duties.

4. **Chief's Quarters.** The U.S. Navy's Chief Petty Officers play a unique and valuable role that is not often present in non-military organizations. Each Chief Petty Officer has an organizational role to play as a member of a watch section, division and department. However, as a whole, the Chief of the Boat and the Chief's Quarters play a huge role in constraining the behavior of the watch sections, coordinating the orders of the VIRGINIA Viable System and enforcing cultural standards.
5. **Safety Rules.** The submarine is a dangerous place to work and live. Over the years, the Submarine Force has developed a set of safety rules and procedures to enable the watch sections to perform their jobs safely and efficiently.

6. **Implicit Threats from the Environment.** The environment presents a shared threat to the crew that is implicit in everything that the crew does. The watch section's perception of this shared threat constrains their own autonomy to ensure that the entire ship and crew is kept safe.

It is difficult to generalize how damping functions are perceived by the VIRGINIA Viable System. Up until this point, we have been discussing the VIRGINIA Viable System as if it was one system, when in fact there are seven VIRGINIA Viable Systems in the U.S. Navy at the writing of this report. Several of the damping function attributes are common to all seven existing VIRGINIA Viable Systems in operation. VIRGINIA crews employ similar standardized forms, safety rules, and timetables. They perceive similar implicit threats from the environment and participate in a decade's long tradition of submarine culture which includes a special status for U.S. Navy Chief Petty Officers. However, each VIRGINIA submarine has its own local culture heavily influenced by the ship's Commanding Officer and other senior leaders. Each ship also has a unique group of Chief Petty Officer's which are knitted together into a "Chief's Quarters" by a Chief of the Boat. The perception of damping functions on each VIRGINIA Viable System will be heavily influenced by the individual ship's Command Climate and Chief's Quarters.

Of course, this is no surprise to the Submarine Force as a whole. The importance of Command Climate and the Chief's Quarters in the combat effectiveness of the ship has long been understood. But this characterization of Command Climate and Chief's Quarters as essential elements of damping functions may provide a new avenue for monitoring the effectiveness of these functions on individual submarines. When damping functions are not functioning well, the outputs of subsystems will tend to oscillate in an unproductive manner from the perspective of the overall VIRGINIA viable system. These oscillations are likely to be visible in all three Viable System dimensions and might be used to diagnose individual submarine damping function problems.

Viable Submarine Watch Section Damping Functions Summary

1. What are the damping functions within the Viable Submarine System?

Damping functions are those functions within the Viable Submarine System that coordinate the actions of the watch sections so that they do not hinder each other's operations. If these functions are perceived as prescribed limitations being imposed by higher level management upon watch section operations, then watch section autonomy is unnecessarily limited and the output of the Viable Submarine System is reduced. However, if these functions are perceived as working for the benefit of the watch sections, oscillations can be minimized while maximizing watch section autonomy.

- a. What are the possible sources of oscillation or conflict between the System Ones?** The primary source of oscillation or conflict arises where the actions of one watch section unnecessarily limit the freedom of action of the other watch sections. For instance, imagine that there are three things that the watch sections as a group are required to complete in 24 hours. If the first two watch sections fail to complete these actions, the remaining watch section may have to spend an inordinate amount of their efforts to meet the desired deadline. Damping functions help each watch section to carry their share of the Viable Submarine System load.
- b. What is present within the Viable Submarine System that provides a harmonizing or mediating effect?** This report identifies and describes six categories of damping functions within the Viable Submarine System. The most important and hardest to quantify is the command climate felt by the watch section and the effective functioning of the chief's quarters.
- c. How are Damping Functions perceived by the Viable Submarine Watch Section Subsystems?** The perceptions of the watch sections will vary from submarine to submarine according to the individual ship's command climate and chief's quarters. Overall, the sustained success of the Submarine Force as a whole is a strong indicator that as a group, damping functions such as command climate and chief's quarters on submarines are functioning well.
- d. Model System Two according to the Viable System Model.** See Figure 12.

Viable Submarine System Control Functions

So far we have been primarily discussing the management of variety in one dimension. In our discussion of viable subsystems, we discussed the filtering of large amounts of environmental variety through VIRGINIA Watch Section Operations and C2. We characterized this in our evolving model as occurring in the horizontal direction. The First Principle of Organization stated that this variety must be balanced. As we model how each watch section works with each other and with higher levels of recursion in the viable system, we are now modeling the management of variety in the vertical direction. Stafford Beer's (1985:84) first axiom of management discusses the management of variety in the vertical direction, "The sum of the horizontal variety disposed by all the operational elements equals the sum of the vertical variety disposed on the six vertical components of corporate cohesion." This is necessary because the reduction of variety filters out information. It is not enough for System C2 elements to receive reports from the watch sections that everything is "ok," it must gain sufficient information to realize when everything is not "ok" before it threatens the viable system. This is true whether the viable system is a shoe store or a submarine! The primary conduit for managing the vertical channels of information is the Viable Submarine System Control function.

We have already discussed several of these vertical channels. In the discussion of viable subsystems, we noted that the watch sections communicate on vertical channels with the Viable Submarine System Control function. In review, these three channels are the resource bargain, performance measurement, and formal rules. The Viable Submarine System Control function provides the resources and the rules. The watch sections produce the results. We have also discussed the role of damping functions in constraining the variety of the watch sections. Viable Submarine System Control functions are responsible for the damping functions - but do best to not dictate damping function behavior to avoid overly restricting watch section autonomy. Most of these channels filter information vertically, what is needed is a channel that amplifies Viable Submarine System Control functions down to the watch sections to balance the variety equation. This is performed by the Viable Submarine System Monitoring function.

Viable Submarine System Monitoring

Viable Submarine System Monitoring is a special function of Viable Submarine System Control⁹. It conducts sporadic audits of watch section operations and reports back to Viable Submarine System Control. These audits amplify Viable Submarine System Control's expectations downward and provide a needed means to assess the reports coming from Watch Section C2 elements. In the U.S. Navy, there is a saying, "expect what you inspect." Viable Submarine System Monitoring exemplifies this sentiment in systems terms. Monitoring functions include (See Figure 13):

1. **Formal Monitored Operations.** Periodically, the Commanding Officer, other officers and chief petty officers (all representing Viable Submarine System Management) conduct formal monitored evolutions while the watch sections are

⁹ In VSM terms the control function is System Three and the monitoring function is System Three Star.

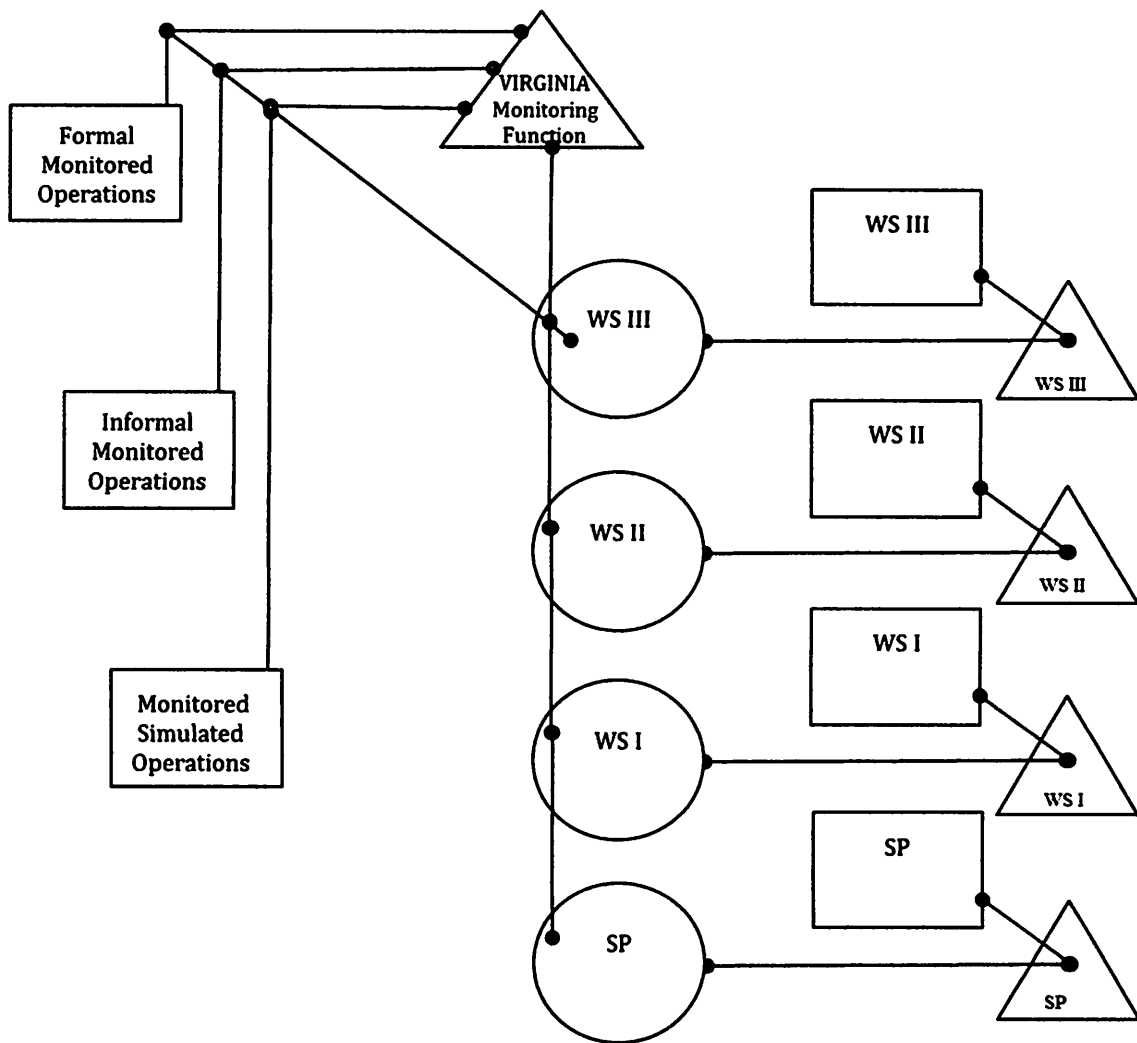


FIGURE 13. VIRGINIA Viable System Monitoring Functions

at work. The results of these evolutions provide insight to the Viable Submarine System's Control function regarding each watch section's strengths and weaknesses. The monitor watches also provide detailed feedback to the watch sections. The feedback becomes amplified because a negative comment made by the Viable Submarine System Control elements (especially the Commanding Officer) quickly spreads throughout the watch sections.

2. **Informal Observation of Operations.** While formal evolutions are scheduled, the officers and the chief petty officers are always observing the actions of the watch sections around them. In fact, when Viable Submarine System Control elements observe something that isn't right (as established by critical damping functions like the ship's chief's quarters or standards of Submarine Force culture) and do not take action, this starts to break down Viable Submarine System Control's support of damping functions. This can be an insidious source of decline in the Command Climate and overall Viable Submarine System performance.

3. **Monitored Simulated Operations.** As mentioned earlier, one of the outputs that the Viable Submarine System must generate is a latent ability to execute operations not actually tasked. For example, all VIRGINIA submarines prepare for wartime missions that rarely occur in peacetime. The only way for the crew to develop proficiency is to practice for these operations. Just as officers and chief petty officers monitor actual evolutions, they must also monitor simulated operations to ensure that instructions and expectations are amplified down to watch sections and so that Viable Submarine System Control is better able to judge the readiness of the watch sections to generate latent outputs.

Viable Submarine System Control

Now that we have a fuller appreciation for the information transfers between the watch sections, the Viable Submarine System Damping functions, and the Viable Submarine System Monitoring functions, we will examine Viable Submarine System Control. Its role is to regulate the operations of the viable subsystems (watch sections) as a whole. Therefore, we start by re-examining our previous description for subsystem regulation. Earlier in Figure 10, we showed how Watch Section C2 regulates Watch Section Operations. As we look at Viable Submarine System Control's regulation of the watch sections, the tasks are the same but now at the next higher level of recursion. The VIRGINIA Viable System is given tasks from the next higher level of operational recursion (the Operational ISIC) and must develop a plan that distributes the submarine's resources across time and operational geography to produce the output that the higher level plan requires. There are opportunities to bargain for resources with the Operational ISIC, there are rules to follow, and a result must be produced. These are the same three information conduits that we described earlier in Figure 9.

As we stated before, any good system of regulation must contain a model of the system that is being regulated. In this case, the planning model must divide the task into elements that can be executed by the submarine watch sections. If a certain element of the plan requires more resources than the watch section can muster, then the plan might call for the watch section to be augmented in some fashion. For example, the plan might contain the order to "Call the Navigator prior to surfacing." The presence of the Navigator adds an additional resource to the watch section. This is how resource bargaining is conducted by Viable Submarine System Control and the Watch Sections.

While we earlier resisted detailed descriptions of how Watch Section C2 conducted its planning, we will examine Viable Submarine System Control in more detail. In Viable System terms, the Control function must create a resource bargain by organizing the activities of the Watch Sections in both space (geographic position) and time. Currently, this plan consists of the navigation plan augmented by the Commanding Officer's Night Orders. The Navigation Plan establishes the Space and Time constraints of the plan. It consists of an approved set of charts that defines the boundaries of the allowed operations and the intended track of the submarine in geography and in time. This is executed through use of a U.S. Navy approved Electronic Chart Display and Information System. The Commanding Officer's Night Orders establish the activities of the plan from Viable Submarine Control to the Watch Sections in 24 hour segments. Second, operational tasking might require the Control function to modify existing Watch Section rules. If this is required, then the Control function prepares and communicates temporary standing

orders to the Watch Sections. Finally, the Control function must establish the criteria for Watch Section success. There is currently no formal structure to this communication. It may be explicitly delineated in the night orders. It might be communicated verbally to the Officers of the Deck. It might be inferred based upon the context of the operation. In this way, the Control function creates and communicates the resource bargain (navigation plan and night orders), modifies the rules as appropriate (temporary standing orders), and defines accountability for Watch Section performance.

On most submarines, there are two planning cycles that operate in parallel. First, the Commanding Officer, Executive Officer and Navigator create and approve the ship's navigation plan. Second, the Commanding Officer, Executive Officer, Chief of the Boat and Department Heads come together to hold a daily operations brief to review and approve the next 24 hour plan. These planning functions are each unique System Control functions.

In classic Viable System Modeling, we would restrict our focus to one dimension. However, our experience in submarine operations informs us that there is another resource bargain being struck by the Submarine Control. When Control convenes a daily operations brief, there is a dimensional bargain for resources being discussed between the technical, operational, and human dimension. Each dimension communicates tasks and rules that the Control function must resolve. A typical daily operations brief will consider all technical, operational, and human tasks that must be performed for the next 24 hours and strike a bargain on how to execute them. For example, some maintenance may be scheduled for the evening watch and the mid-watch may be tasked to be ahead of the planned track, so the submarine can slow down in the morning and run a series of training simulations or drills, all while the ship is in transit to an assigned mission. It is the function of Control to strike this bargain and communicate back to the appropriate operational or administrative ISIC if a rule or plan cannot be executed as tasked. The Daily Operations Brief is the Regulator of the Control Function. Figure 14 shows the Control regulation of the watch sections from a Viable System perspective.

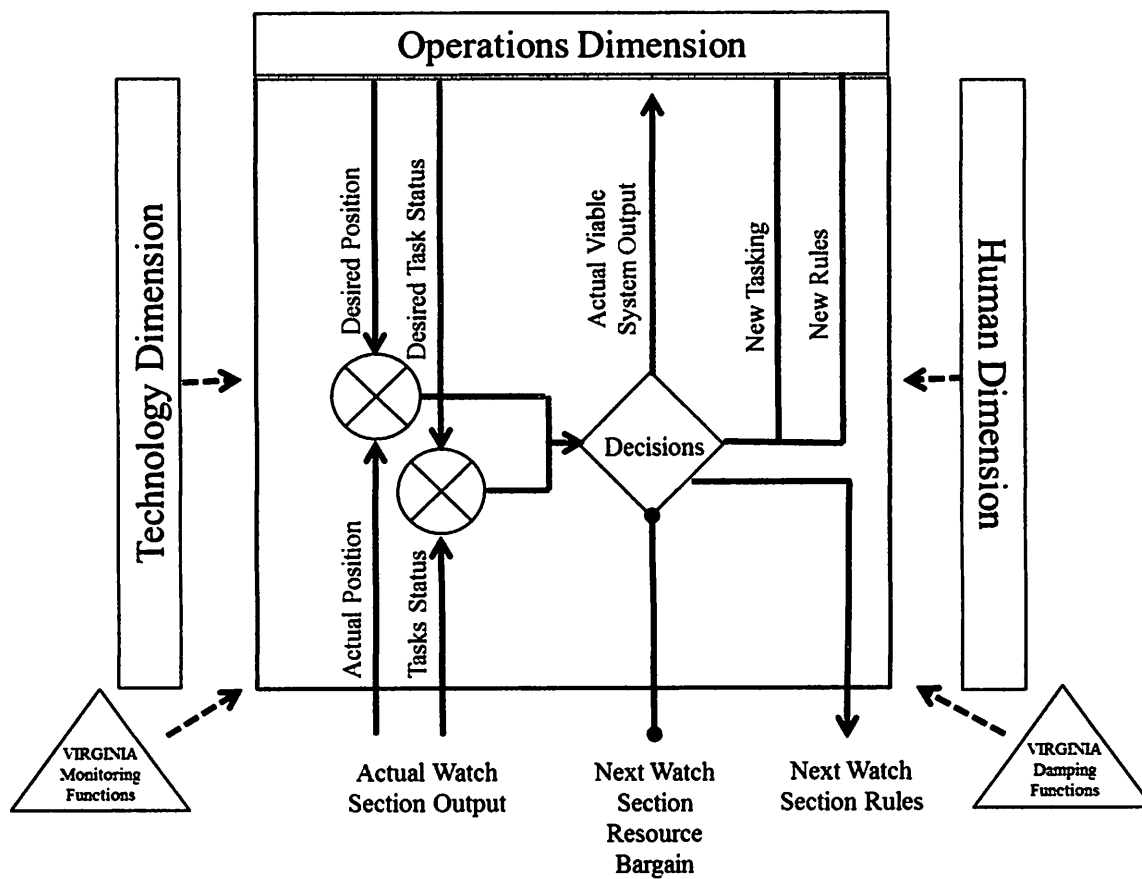


FIGURE 14. Viable Submarine System Regulation - Bargaining in Three Dimensions

Viable Submarine System Control Summary

- 1. What exercises the Control over the watch sections within the Viable Submarine System?** The supervisors within the Viable Submarine System collectively comprise the Viable Submarine System Control Function.

a. What are the functions of Viable Submarine System Control function?

- i. Communication with the operational ISIC about tasks.
- ii. Receipt of reports from Watch Section Monitoring and Damping functions.
- iii. Resource bargaining with the Watch Sections,
- iv. Regulation of Watch Section Operations

Of these management functions, most are absorbed in the daily work of submarine supervisors. Only the regulation function has a formal structure embodied in the ship's Daily Operations Brief.

- b. How does the Control function exercise authority?** Authority is communicated in the ship's Navigation Plan, the Commanding Officer's Night Orders and augmented by verbal orders from appropriate submarine supervisors.
- c. How are bargains for resources with each Watch Section carried out?** The Control function, as represented in the Commanding Officer, Executive Officer, Chief of the Boat and Department Heads, typically strikes the bargain for resources by estimating the capabilities of the individual watch sections (and key individuals in the watch sections) as well as the capabilities of the submarine, as a whole, and chooses tasks that they assess to be within the capability of the watch sections assigned. Watch Sections are expected to ask for help if they find that they cannot achieve the desired results.
- d. Who is responsible for the performance of each Watch Section?** The Officer of the Deck is responsible for the performance of the watch section.
- e. How does Control monitor the performance of each Watch Section?** Submarines exercise formal monitor programs, informal monitoring, and monitoring of simulated operations. All three are required to provide Control with sufficient information about Watch Section operations and to amplify Management expectations throughout the ship.
- f. What is the relationship between Submarine Control and the watch sections? How much autonomy does each watch section exercise?** The

officers exercising the submarine Control function are senior in rank and typically have more experience in submarine operations than the watch sections. There is a clear lead (control) – follow (watch section) relationship.

The submarine's environment is dynamic. As a result, the watch sections must be granted sufficient autonomy to adapt to the changing environment while striving to achieve the tasks set out before them. For example, on a surface transit, Submarine Control may task the Watch Section to arrive at Point B at a specified time. However, Control cannot predict dynamic conditions such as weather and the position of interfering surface vessels. As a result, submarine navigation plans try to identify all available navigable water in order to give the watch section maximum autonomy. The actual autonomy exercised by watch sections will depend on the circumstances and the actual ship-in-focus.

VIRGINIA Viable System Intelligence Functions

Most of the Viable Submarine System functions we have been discussing are focused internally on ensuring that the viable subsystems optimize their production. This is insufficient for submarine viability. Someone needs to be looking out at what is occurring in the future submarine environment and preparing the Viable Submarine System for challenges to its viability. Remember, our use of the term “environment” means more than keeping a weather eye out to changes in the physical environment. The VIRGINIA Viable System environment is everything outside of the VIRGINIA System itself. This includes potential orders from the submarine’s Operational ISIC, potential actions by an adversary as well as changes in the ship’s physical environment. Additionally, the VIRGINIA Viable System is accountable in three dimensions. This means that the system must be responsive to environmental changes in all three dimensions.

The Intelligence function monitors the future environment of the VIRGINIA Viable System. If we look back at Figure 11, we can see the collective environment of the viable subsystems is already modeled. This environment is very short term. The watch sections typically only look 24 hours ahead to help prepare the oncoming watches and to think about what they will be tasked to perform next. The VIRGINIA Viable System Intelligence function looks across a much larger conceptual and time horizon to anticipate future events.

The Intelligence function’s look into the future environment works best if it considers two types of futures. First, what are the expected future challenges that the VIRGINIA Viable System must face? Surrounding this “expected” future is a much larger possible future that represents the unexpected but potential futures the VIRGINIA may face. Consideration of expected missions is a relatively straightforward task of drawing together the information needed, developing the plans and communicating to the watch sections a plan for their watch. (The fact that it is straightforward does not mean that it isn’t time consuming and challenging in its own right.) Consideration of potential futures is much more difficult and reliant upon individual skill and experiences. The U.S. Navy urges the use of Operational Risk Management techniques to try and prepare for alternative futures. We often talk about planning from a perspective of risk. It is just as important to discuss planning from a perspective of opportunity. Figure 15 shows the Intelligence function as it looks into the future of VIRGINIA’s Viable System risks and opportunities.

It is instructive to compare perceptions of planning in the Submarine Force from the perspective of our VIRGINIA Viable Intelligence functions. Some submarines might perceive their environmental future as relatively stable. As a result, submarine crews with perceived stable environments are more likely to engage in long range planning and look for risks and opportunities several weeks or months into the future. This might be very different from other submarines who perceive the future as very unpredictable. These submarines are likely to avoid planning too far ahead because it is perceived as a waste of time. A comparison of what this might look like in a Viable System model is shown in Figure 16. The submarine with the perceived stable future has a longer expected event horizon. The submarine with the perceived unstable environment truncates their planning horizon

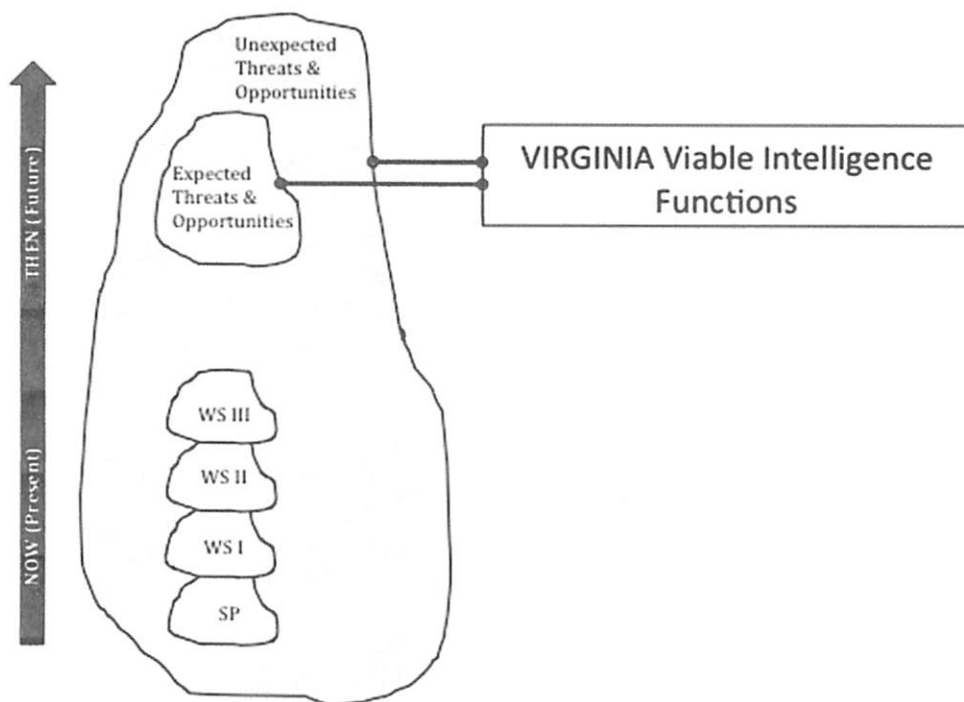


FIGURE 15. VIRGINIA Viable Intelligence Functions

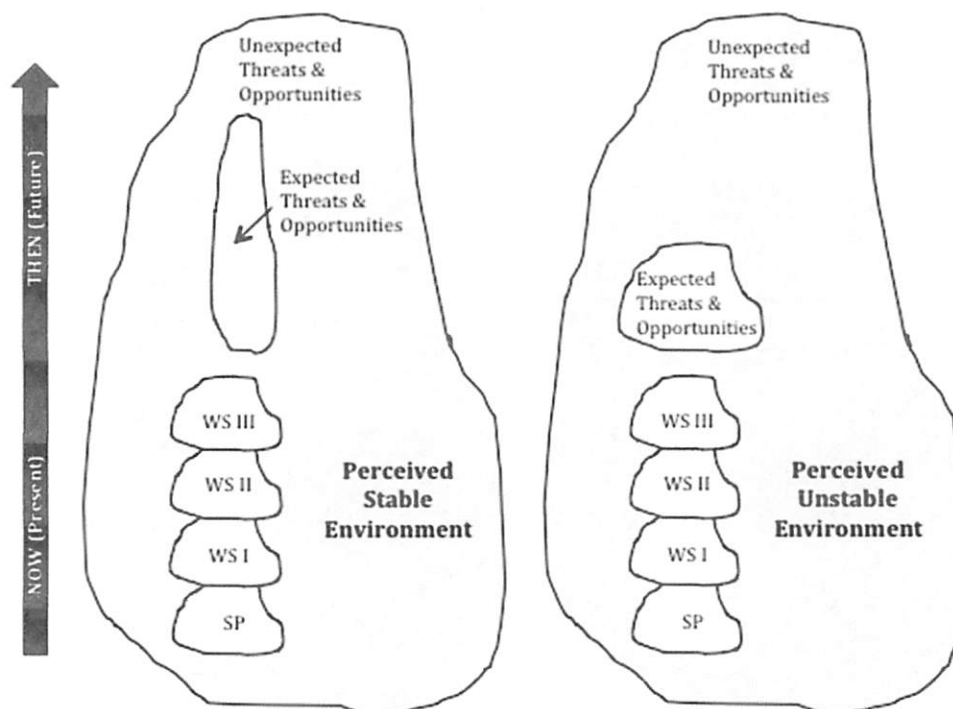


FIGURE 16. Varying Perceptions of Environmental Stability

Another interesting feature of the VIRGINIA Viable Intelligence function is the fact that most information about the future comes through a relatively narrow channel – messages sent to submarines at sea. This constrains the Intelligence function's ability to perceive the unexpected. On the other hand, the VIRGINIA has access to more local knowledge (with less time latency) than operational authorities in the chain of command. As a result, the VIRGINIA Viable System places a premium on being able to rapidly plan, adapt the submarine to changes in the environment, and exploit local knowledge while it is dependent upon outside operational authorities to provide information that is outside of VIRGINIA's organic sensor range.

As we discussed before, the VIRGINIA Viable System does not have the luxury of focusing on only one systems dimension at a time. This requires us to consider the interactions of the three dimensional environments within which the VIRGINIA Viable Systems exists. The future environment of the VIRGINIA Viable System is a combination of three overlapping environments (Figure 17). Each dimension has its own expected threats and opportunities. The overlap occurs because each dimension interacts with the others. For example, imagine there is a piece of equipment that is not fully functioning. The opportunity to repair this equipment is part of the ship's future environment (opportunity). If, however, the equipment repair does not go well, the

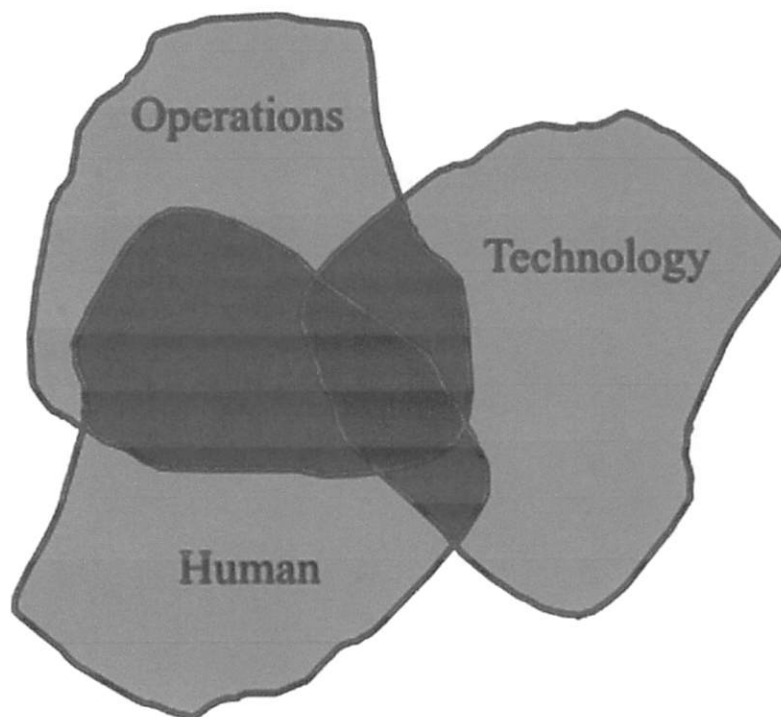


FIGURE 17. Dimensional Overlap in Environmental Futures

equipment may be totally out of commission (risk). If this equipment is somehow limiting the ship's operational capabilities, then there is a risk/opportunity decision to be made regarding the future environment (overlapping the technological and operational

environments). Given the limited size of the VIRGINIA crew, if a significant repair team effort is launched, the watch bill may be affected causing several crew members to stand more watch than normally desirable (now an overlap with the human dimension is seen). These risk-versus-gain decisions are a common part of the VIRGINIA Viable System's Intelligence function. The VIRGINIA Viable System (operational dimension) must deal with all the risks and opportunities that come within the operational boundary.

We said earlier, that any good regulator of a system must have a model of the system being regulated (Ashby-Conant Theorem). The role of the Command (next section), Intelligence, and Control functions are to regulate the VIRGINIA Viable System as a whole. In order to facilitate this regulation, the Intelligence function must have a model of the VIRGINIA Viable System inside it. This is what enables the higher-level functions of the Viable System to be self-aware. The purpose of this self-awareness is to test the Viable System's readiness for future environmental challenges.

Viable System Intelligence System Summary

- 1. What is the Intelligence Function with the Viable Submarine System?** The Intelligence function looks outside the viable system and tests the ability to meet future risks and opportunities.
 - a. What are all the Intelligence functions within the information architecture?** There are three components to the Intelligence function:
 - i.** A communication channel with the likely future.
 - ii.** A communication channel with an unlikely future that might affect future submarine system viability.
 - iii.** A self-awareness of internal model of the viable system that the intelligence function uses to test the viability of the submarine system against future alternatives.
 - b. How far ahead in time do these activities consider?** There is no set time span for these activities. When the anticipated future is relatively stable or when there are sufficient resources available, the planning horizon may be months or even years in advance. When the environment is especially hard to predict and resources are strained, the planning horizon is likely to be much shorter.
 - c. How well do these activities support adaptation of the Viable Submarine System to the future?** This is a difficult question to answer. The demonstrated long-term viability of the basic submarine system indicates that this function is adequately addressed. On the other hand, it is hard to point to specific aspects of the Submarine Force doctrine or organization that supports this function with the notable exception of Operational Risk Management. We speculate that a tremendous amplifier of U.S. submarine viability is its technological advantage against virtually all adversaries. In many ways, U.S. submarines can ignore many aspects of their environment. Should this advantage degrade, then we predict that the Intelligence function would sense greater risk and submarine viability would be more difficult to maintain.
 - d. How effectively is the Intelligence function monitoring what is happening in the environment? How well are trends monitored?** This question will change dramatically from submarine to submarine and one can only point again to the long-term success of the Submarine Force to say that on the whole it must be adequately addressed.
 - e. Is System Four open to novelty?** Same answer as above.
 - f. How well does the Viable Submarine System bring together the internal and external information for decision making (adaptation mechanism)?** While there is a formal structure for watch section operations (pre-watch tour, turn over checklists, etc.), there is no formal structure for bringing together internal and external information for long-term decision making. Most

submarines have a daily operations brief, but its intent is not long range planning or assessment. The success or failure of any given submarine in this area is dependent upon the proclivities of the officers and crew to plan for the submarine's future.

- g. How does the Intelligence function alert Command to urgent developments in the information architecture?** Urgent developments are typically sensed by members of the watch section in the performance of their duties. There are various standing orders and regulations that require Commanding Officer notification of various events such as equipment failures, detection of threats, receipt of operationally urgent messages or tasking, etc.

VIRGINIA Viable System Command Functions

The VIRGINIA Viable System Command function is the one function that is embodied in a single person, the Commanding Officer. While all of the other functions may be assisted by other members of the crew, the Commanding Officer embodies the identity of the Viable System as a whole. The Commanding Officer has three tasks to complete from a viable systems perspective (Hoverstadt, 2008):

- **Command Decision:** Choose the course that the organization will take within its environment. This requires the ability to avoid unnecessary distractions and stay the course or adapt as the needs of the environment dictate.
- **Viable Submarine Identity:** Create, sustain or re-create the identity of the submarine as circumstances dictate.
- **The Viable Submarine System as a Subsystem of a Greater Whole:** Maintain sufficient awareness of the role of the submarine in the higher-level organization to ensure that the submarine fulfills its organizational tasking.

Command Decision

The Commanding Officer is often the most experienced submariner on the crew and the capacity of submarine commanding officers to absorb information and make successful decisions is truly impressive. And yet, all commanding officers are limited in the amount of information that can be absorbed. No Commanding Officer can possibly absorb the immense amount of information that is being communicated from the environment and circulating throughout the Submarine Viable System. As discussed earlier in the Watch Section Subsystem, there must be a balance struck in filtering information that goes to the Commanding Officer and amplifying the intent of the Commanding Officer to the Submarine Viable System.

The purpose of the viable system's vertical structure is to reduce the variety of information arising from the environment and the viable system being managed to a low enough level that the Commanding Officer can make the decisions necessary ensure continued system viability. As a result, the Commanding Office must stay alert for signals from the crew that all is not well. Since formal channels of information are designed to filter information, too much or the wrong information might be filtered. To account for this possibility, the Commanding Officer must be ready for information communicated through unofficial channels. Keep in mind the Viable Submarine System pays close attention to the Commanding Officer's actions. The people in the system from the watch sections to the Executive Officer are all aware that information must be filtered on its way to the Commanding Officer. This is not a choice. It is a necessity. Every crewmember in every subsystem we have discussed makes choices about what to filter and what not to filter based upon their perception of what higher level systems want to hear. This is communicated most strongly by what the Commanding Officer says and does (and doesn't say and doesn't do). When the individual traits and personality of the Commanding Officer align with the needs of the Viable Submarine System, the system is more likely to make the right choices when information is filtered and the submarine

system is more likely to be successful in its tasking. When the Commanding Officer's traits and personality are not aligned with the needs of the Viable Submarine System, the wrong information is likely to be filtered and viability is threatened. The old saying "don't shoot the messenger" now has viable system justification!

The immense filtering of information also creates a decision making dilemma. How can the Commanding Officer judge the adequacy of a proposed course of action without diving into all the details that went into the plan's construction? Viable systems solve this dilemma with what Espejo (1989) calls the "adaptation mechanism." The Control function focuses on the inside of the Viable Submarine System. It is in charge of establishing the plan, monitoring watch section execution and holding them accountable for viable system performance. When analyzing what the viable system should do in the future, the Control function filters and reduces the information at its disposal to recommendations for Command. Without filtering, Command would be awash in details best delegated to others in the organization. However, information is lost whenever filtering occurs, so how does Command judge if the plan presented by Control is adequate?

This dilemma is solved by the Intelligence function. The Intelligence function focuses on the environment within which the Viable Submarine System must succeed. The Intelligence function looks at information streams relating to likely future events, considers the opportunities and threats present in unexpected changes and the capabilities of the Viable Submarine System as a whole, and recommends courses of action to the Command about what the Viable Submarine System should do. This effectively reduces the variety of the question from "What should the system do?" to "Is the plan presented by Control sufficient for the Submarine to succeed in its future tasking?" When differences arise between Intelligence and Control, Command is able to focus on the pieces of information (and the related uncertainty of that information) that are most relevant to choosing the course of action under consideration. In fact, when Intelligence and Control agree, Command may exercise the role of "devil's advocate" to elicit debate. In this way, Command can bring information to light that best tests the soundness of the recommended course of action.

Viable Submarine Identity

In systems thinking, a system without identity cannot survive – indeed, it does not exist. By definition, a system is a collection of parts that is organized to achieve an intended purpose. The system's awareness of its own purpose creates its identity. While all members of the submarine crew collectively contribute to the Viable Submarine System's identity, the Commanding Officer plays a unique and vital role. First, to superiors in each of the dimensions, the Commanding Officer represents the submarine. The resource bargains struck and the accountability for tasking falls directly on the Commanding Officer's shoulders. From the perspective of the crew, the Commanding Officer communicates the Viable Submarine System's dedication to the submarine's purpose in every action and every word. A shared sense of identity contributes to morale, shared pride in the submarine's work and a willingness of the members of the crew to sacrifice their own individual desires to the higher purpose that the Viable Submarine System represents.

The Viable Submarine System as a Subsystem of a Greater Whole

As a military organization, the submarine's survival is subservient to the higher purpose that the submarine serves. Just as the desires of individuals are subservient to the identity and purpose of the Viable Submarine System, the needs of the submarine are subservient to the needs of the next higher naval organization's identity and purpose. In systems terms, we talk about avoiding sub-optimization. In a self-aware viable system, the shared sense of purpose creates a willingness to find the optimal balance between individual needs and the needs of the greater whole.

The Commanding Officer has unique access to interactions with higher levels in the chain of command. It is incumbent upon the Commanding Officer to apply this knowledge to command decisions and communicate it to the Viable Submarine System, as appropriate. This is particularly true on submarines given the limited opportunities to communicate once underway. In a formal sense, this connection to the higher-level organization is represented by the task/resource bargain, the rules and the accountability to which the Viable Submarine System is held. It is incumbent on higher-level command functions to create a sense of identity that represents the greater whole.

VIRGINIA Viable System Command Summary

2. What is the Command function within the Viable Submarine System?

- a. **Who is it and how does it act?** The Commanding Officer embodies the Command function on a submarine. The Commanding Officer acts to make all critical decisions that affect the viability of the submarine. These decisions take the form of direct orders (both oral and written) and approval of plans and decisions created by the Control function.
- b. **Does Command embody the "identity" of the entire Viable Submarine System to the next higher level of the system (Recursion 0)?** The Commanding Officer is the sole person who can speak for the entire Viable Submarine System.
- c. **How do the expectations of Command affect the perceptions of Intelligence?** The Intelligence function must decide how much and how often to sample the future environment. There is also a need to decide how much effort to expend on the likely future and how much effort on the risk and opportunities of less likely events. The decision-making style of the Commanding Officer will largely influence how much effort Intelligence places on various probes of the future environment.
- d. **How do the expectations of Command affect the relationship between Intelligence and Control?** Command's use of the adaptation mechanism will heavily influence the relationship between Intelligence and Control. In fact, since there is no formal Intelligence organizational structure on the submarine, there is great risk that there will be little consideration of the Intelligence function unless the Commanding Officer demands it. A

healthy, constructive debate between Intelligence and Control is the key to long-term system viability.

- e. **Does Command share an identity with each Watch Section Subsystem in the Viable Submarine System?** The Commanding Officer's relationship with the Watch Section Subsystems is a key component of the communication of the submarine's purpose and identity. The Commanding Officer spends time interacting with the next higher operational recursion in order to anticipate the needs of and understand the identity of the higher-level system in which the submarine is embedded. The Commanding Officer and the Watch Section Subsystems need the same systems connection so the watch sections can anticipate the needs and understand the identity of the Viable Submarine System.

Viable Submarine System Model in Action – Submarine Missile Strike

This section considers how the Viable Submarine System Model would be used to analyze a postulated submarine operational tasking. The Viable Submarine System must be viewed as a dynamic, holistic system in order to appreciate how the parts of the model combine to achieve its intended purpose. This sample mission will serve the purpose of demonstrating the Viable Submarine System Model in a dynamic, holistic scenario. We will step through the scenario in discrete time increments and describe what the various parts of the system are doing.

Initial Conditions

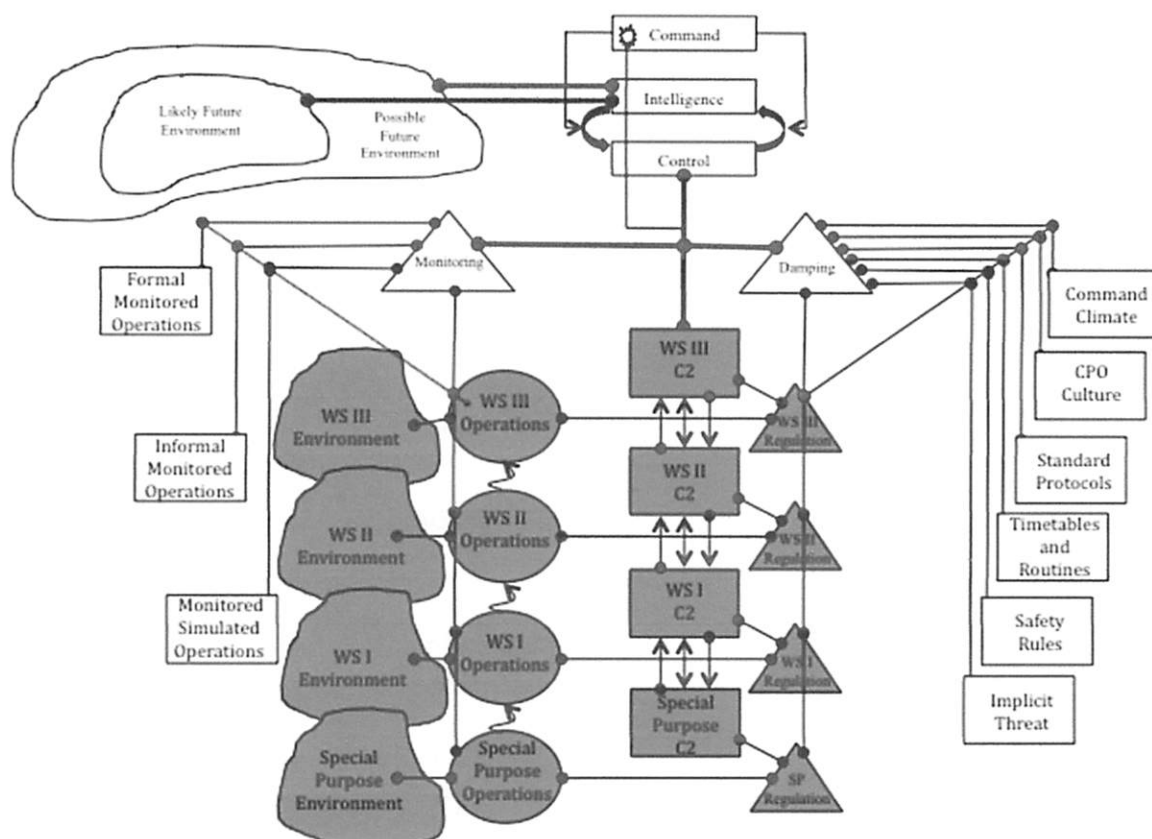


FIGURE 18. Initial Conditions

Function	Focus
Command	Transit
Intelligence	Possible Futures
Control	Watch Section Execution of Transit Plan
Damping	Watch Section Interactions
Monitoring	Watch Section Operations
Watch Section Subsystem	Execution of Transit

USS North Dakota (SSN -784) is in transit from the Mediterranean to its homeport in Groton, CT. She has already passed through the Straits of Gibraltar and is heading for homeport. She has scheduled a series of training events for the return transit.

Receipt of Tasking (Step 1)

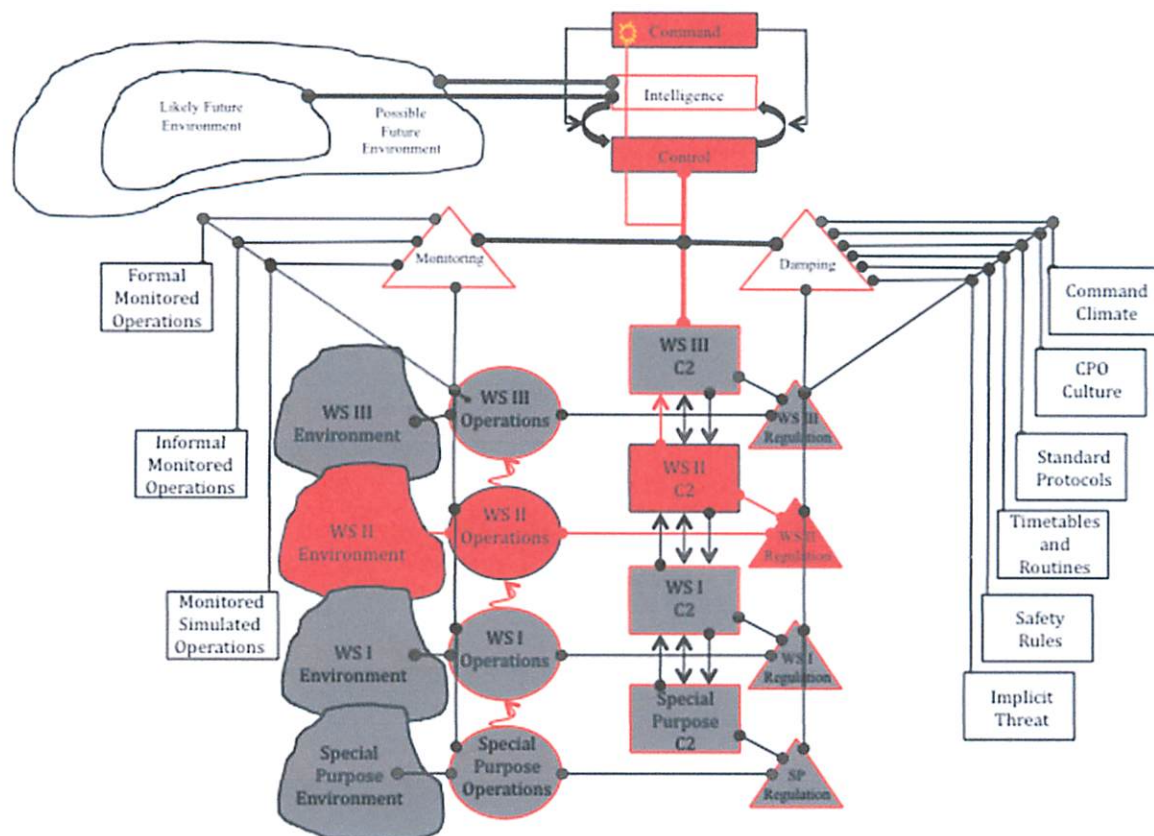


FIGURE 19. Receipt of Tasking

Function	Primary Focus
Command	Missile Task
Intelligence	Possible Futures w/Missile Task
Control	Watch Section Execution and Missile Task
Damping	Watch Section Interactions (and missile task)
Monitoring	Watch Section Operations (and missile task)
Watch Section Subsystem	Execution of Transit (and missile task)

The North Dakota's Operational ISIC has drafted a tasking message telling the submarine to transit to a designated location off the coast of Africa and prepare for a missile launch against a terrorist target. As the ISIC transmits the message, the tasking information becomes part of an environmental information channel that the North Dakota routinely monitors. Upon the submarine's next periscope depth trip, the message is received from the submarine's environment by Watch Section II and communicated to the Officer of the Deck. The Officer of the Deck recognizes the importance of the message and follows standard submarine protocol in forwarding the message to the ship's Assistant Navigator, Navigator, Executive Officer and Commanding Officer. While certain functions are formally activated (highlighted in red), Watch Section II shares the knowledge with the entire system (outlined in red) that tasking of a potential missile launch is onboard.

Analysis of Tasking (Step 2)

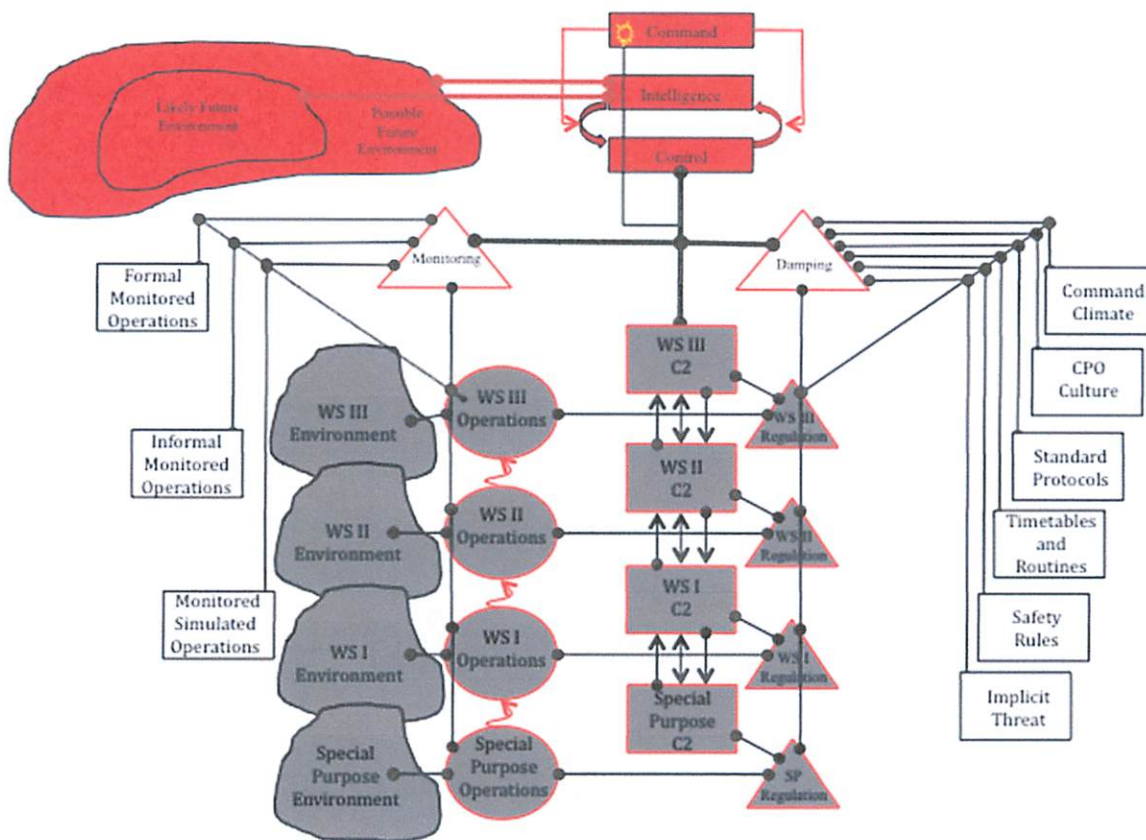


FIGURE 20. Analysis of Tasking

Function	Primary Focus
Command	Is Missile Task Executable?
Intelligence	What Possible Missile Task Environments Are Important?
Control	Are the Watch Sections Ready to Execute Missile Launch?
Damping	Watch Section Transit Interactions (and missile task)
Monitoring	Watch Section Transit Operations (and missile task)
Watch Section Subsystem	Execution of Transit (and missile task)

Command tasks the Intelligence and Control functions to consider the ability of the submarine to execute the assigned task. This is part of the resource bargain being struck with the Operational ISIC. The Intelligence function looks at the external environment. The Control function considers the capabilities of the ship. Their discussion on whether the submarine is able to execute the task in the anticipated environment informs Command. Command decides that the task is executable. The rest of the North Dakota's Viable System remains alert that a change in plans is coming.

Acknowledgement of Tasking (Step 3)

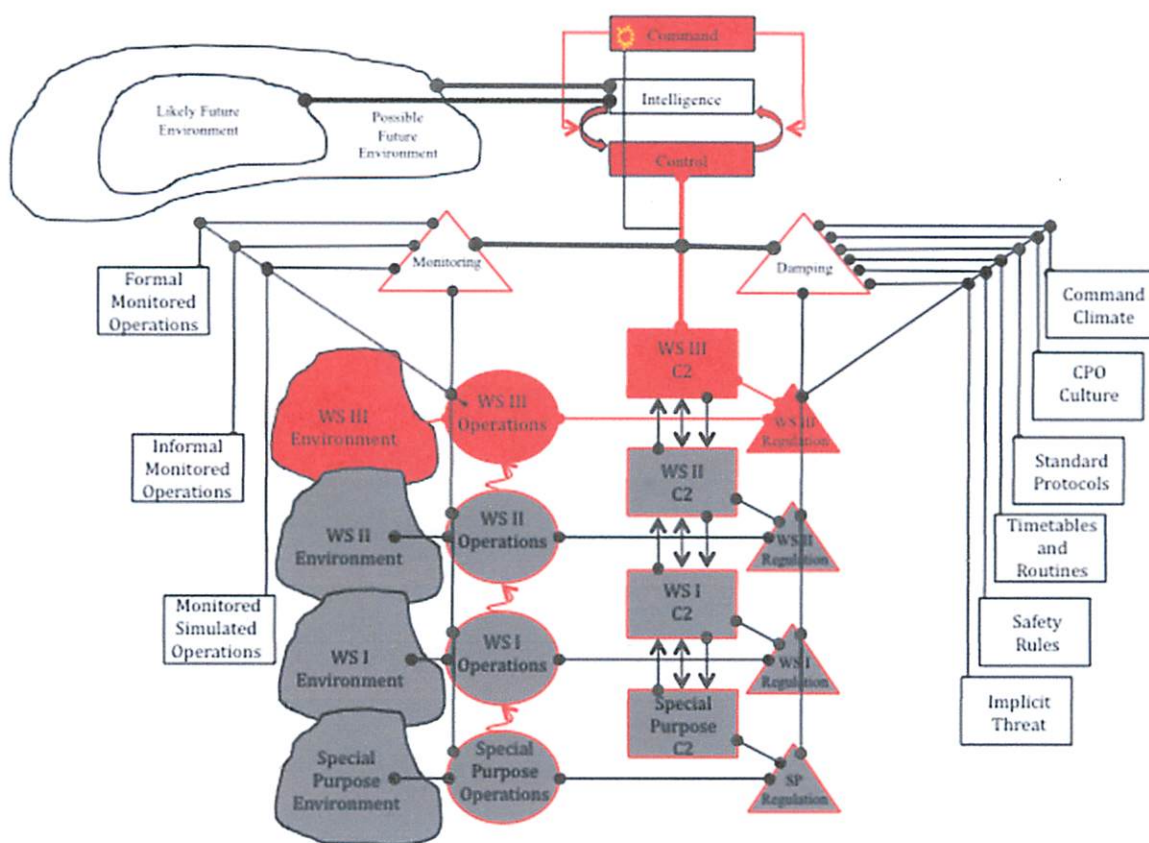


FIGURE 21. Acknowledgement of Tasking

Function	Primary Focus
Command	Acknowledge Missile Task
Intelligence	Possible Missile Task Environments
Control	Direct WS III to Acknowledge Missile Task
Damping	Watch Section Transit Interactions (and missile task)
Monitoring	Watch Section Transit Operations (and missile task)
Watch Section Subsystem	Acknowledge Missile Task and Resume Transit

Command directs the Control function to transmit a message to the Operational ISIC that the missile launch task is executable. In reality, the Commanding Officer often performs Control functions. The CO may just walk into the Control Room and direct the Watch Section III Officer of the Deck to make preparations to come to Periscope Depth and transmit an acknowledgment to the Operational ISIC. The Officer of the Deck works with his Watch Section Operations to carry out the Commanding Officer's orders. In the end, a message is transmitted into the North Dakota's Watch Section III environment for the ship's Operational ISIC.

Detailed Planning (Step 4)

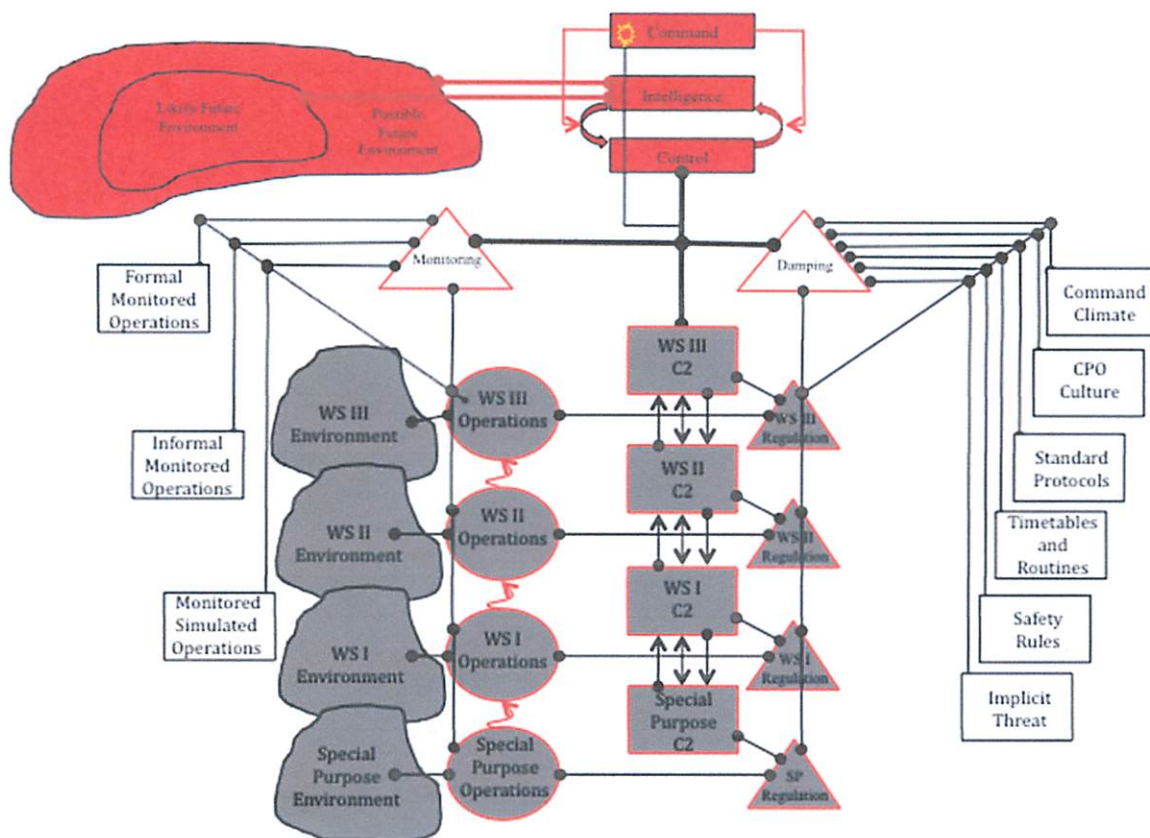


FIGURE 22. Detailed Planning

Function	Primary Focus
Command	Approve the Plan for Missile Task
Intelligence	Will the Plan Succeed in the Future Environment?
Control	Develop a Plan for Missile Task Execution
Damping	Watch Section Transit Interactions (and missile task)
Monitoring	Watch Section Transit Operations (and missile task)
Watch Section Subsystem	Execute Transit

The development and approval of the detailed plan is similar to Step 2 but requires far greater effort. The Control function must break the plan into segments in time and space to direct the actions of the Watch Section Subsystems. Knowledge in all three dimensions (operational, technological, and human) must be combined to create the resource bargains that will ensure that the ship's crew and equipment are in the best possible posture to execute the missile strike. The plan should also include needed Damping or Monitoring function actions as required to ensure the watch sections are ready. Intelligence challenges Control's plan with "what if" questions to see if the plan will succeed in the likely missile launch environment in order to aid the Command Decision. The degree to which this challenge will probe into unlikely but important scenarios will be determined by the time available and the personality of the people

involved (especially the Commanding Officer). The Commanding Officer approves the plan.

Communicate the Plan throughout the Viable System (Step 5)

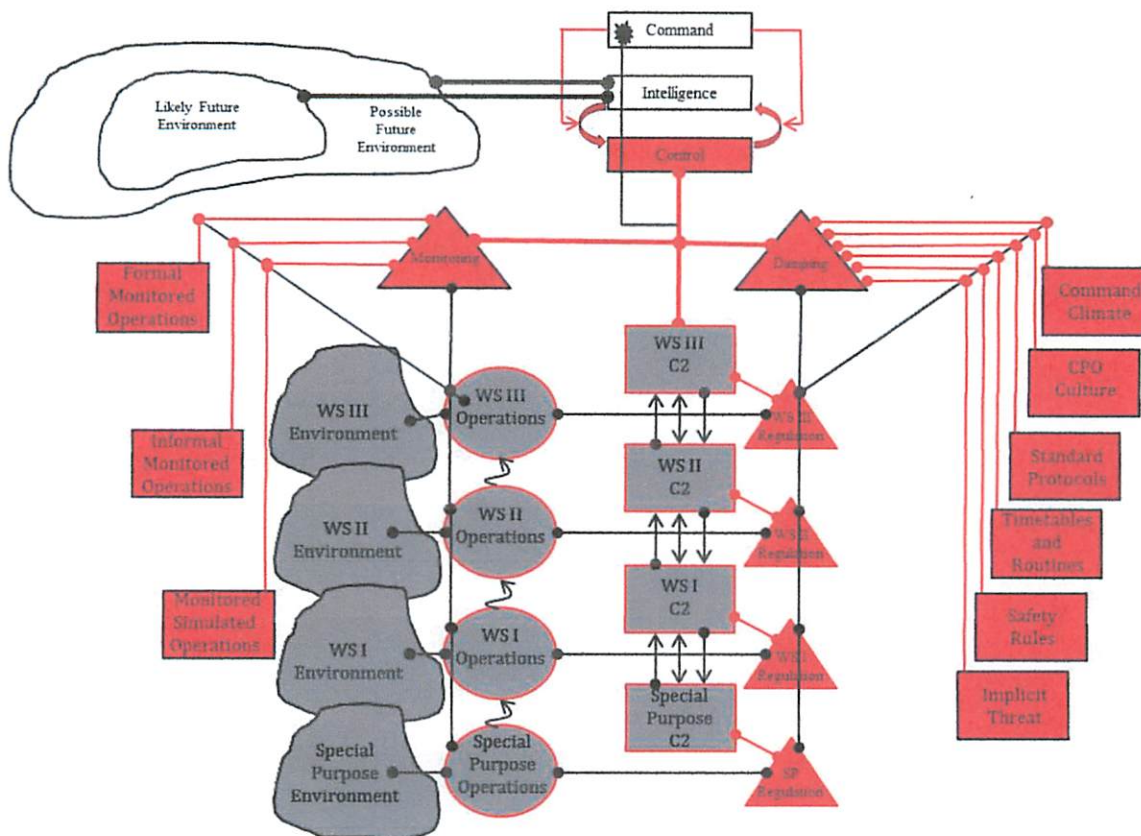


FIGURE 23. Communicate the Plan throughout the Viable System

Function	Primary Focus
Command	Communicate the Plan for Missile Task
Intelligence	Will the Plan Succeed in the Future Environment?
Control	Communicate the Plan for Missile Plan Execution
Damping	New Damping Requirements for Missile Plan
Monitoring	New Monitoring Tasks for Missile Plan
Watch Section Subsystem	New Missile Plan Received in Watch Section Regulatory Models. Watch Section Command and Control Notified.

The approved plan must be distributed throughout the North Dakota's Viable System, but where exactly does it go? The above diagram highlights three areas of particular interest. First, the plan is added to the Watch Section regulatory models. This is done in the form of an updated navigation chart and night orders that direct the watch sections when to begin the execution of the plan. The Monitoring and Damping functions must restructure what evolution to observe and what timetables, routines and safety rules need to be modified (or emphasized). The entire system feels the effect of the implied threat that the targeted terrorist camp represents.

Let's pause to consider exactly where the North Dakota's plan physically resides. First, it resides in the navigation technology as an approved digital chart with instructions for the Watch Section Subsystems. Second, it is published in 24 hour segments through the Commanding Officer's Night Orders. The combination of these two repositories of information provides the minimum essential elements of tasking, rules and accountability that give the watch section purpose. Beyond that, the contents of the future plan are kept in an ad hoc fashion by North Dakota's Control function, reviewed daily and approved for inclusion in the next publishing of the Commanding Officer's Night Orders.

Different plans require different skills to be employed by the watch sections. If the skills required are well within the skills of the watch section, then the plan can be delivered and executed without significant watch section explanation. If the skills are not routinely used, then the watch section may require briefings and practice sessions to be ready to execute. If this is the case, the preparation of the watch sections should be part of the plan.

Execute the Plan (Step 6)

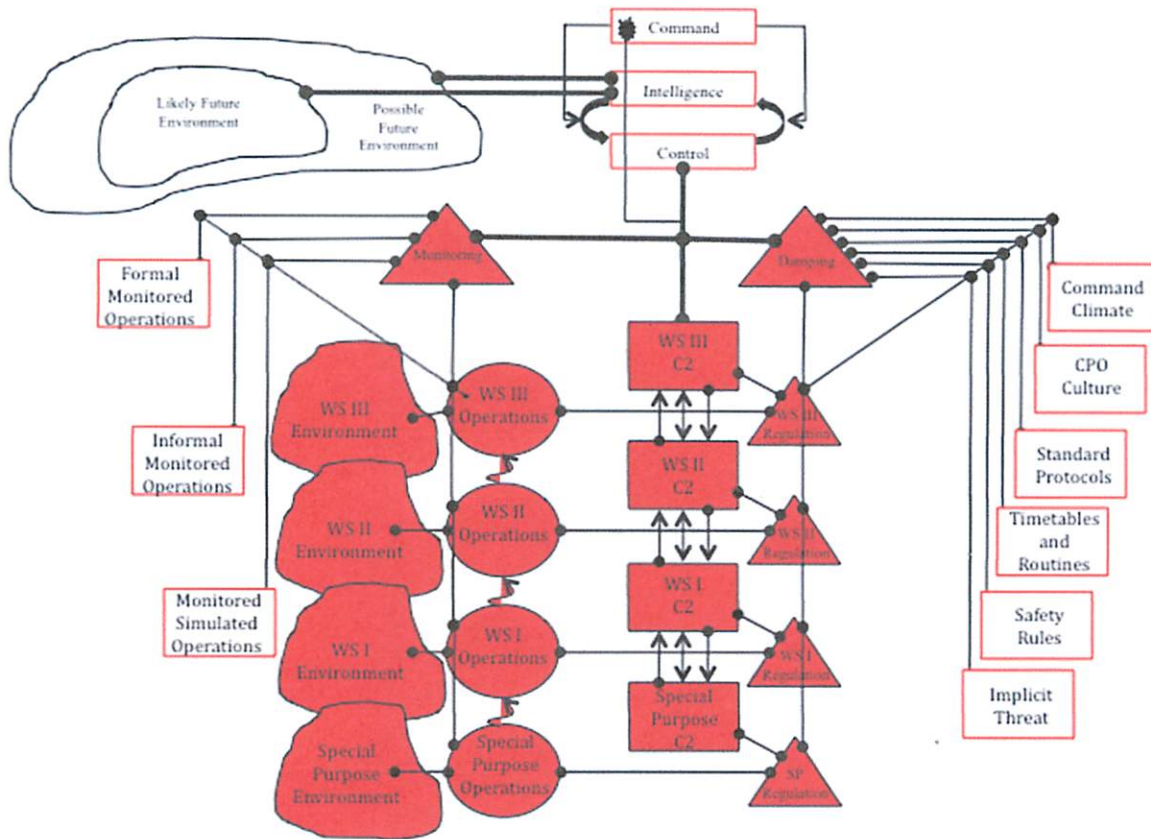


FIGURE 24. Execute the Plan

Function	Primary Focus
Command	Monitor the Execution of the Plan by the Viable System
Intelligence	Monitor the Environment for Changes
Control	Monitor the Execution of the Plan by the Watch Sections
Damping	Damp Oscillations As the Watch Sections Execute the Plan
Monitoring	Observe Watch Section Operations
Watch Section Subsystem	Execute the Plan

The execution of the plan allows the Viable Submarine System to return to its natural state. The watch sections are executing planned operations (producing the output of the system) and the remainder of the viable system is monitoring both the system and the environment for needed adaptations. The USS North Dakota begins her transit to the launch site and readies her missile battery. In the military, the monitoring functions are called the “Battle Rhythm” of the operations. On a schedule, typically once a day, the key supervisors of the Viable Submarine System (Command, Intelligence, and Control) meet to review the output of the watch sections. They consider whether the USS North Dakota will be on station (at the required geographic location) in sufficient time and review the readiness of the ship’s missiles. The comparison of the actual output to the desired output constitutes the essential negative feedback loop. The error signal

generated is then applied to the direction that the oncoming watch sections receive in the next set of night orders. The output of the watch sections must also be compiled and communicated to the operational ISIC. The content and timing of this information is dictated in the initial tasking.

The Daily Operations brief generates immediate feedback for the watch section, but there are other feedback loops in play. The submarine crew may retain some feedback for use for the next time they receive missile launch tasking. The submarine may also collect lessons learned for communication back to higher authority for use by other submarines.

The North Dakota's mission culminates with the actual launch of the missiles by the ship.

Report Results (Step 7)

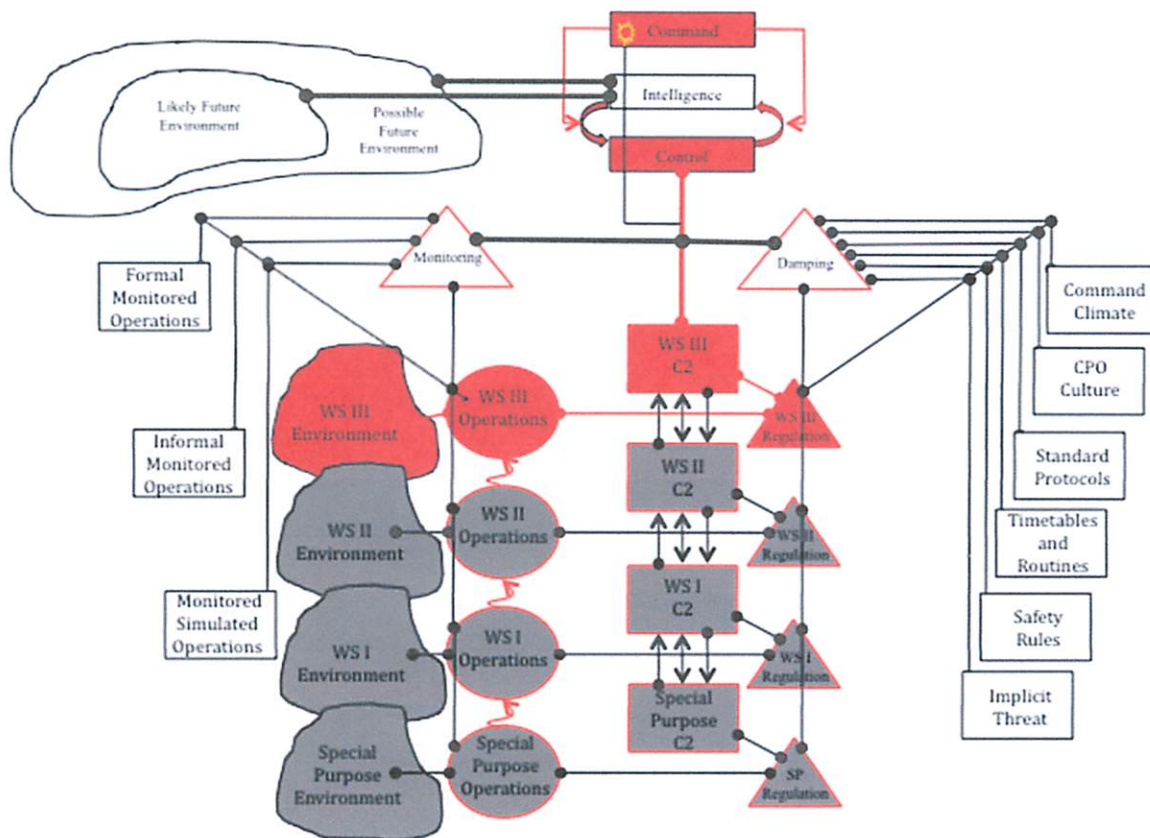


FIGURE 25. Report Results

Function	Primary Focus
Command	Report Results of Missile Task
Intelligence	Future Possible Tasking
Control	Direct WS III to Send Missile Report Message
Damping	Watch Section Return to Previous Transit
Monitoring	Watch Section Return to Previous Transit
Watch Section Subsystem	Report Missile Results and Resume Transit

The results of the launch are reported to higher authority and the submarine continues on with its planned transit home.

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